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A REVIEW OF COST
PERFORMANCE INDEX STABILITY

THESIS

Scott R. Heise, Captain, USAF

AFIT/GSM/LSY/91S-12

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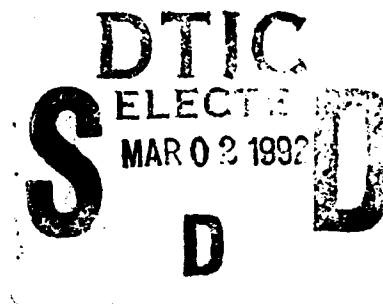
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AFIT/GSM/LSY/91S-12

A REVIEW OF COST PERFORMANCE INDEX STABILITY

THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Systems Management

Scott R. Heise, B.S.

Captain, USAF

September 1991

Approved for public release: Distribution unlimited

Preface

The purpose of this study was to review the different approaches currently used for determining when Cost Performance Index (CPI) stability occurs. In demonstrating that (of cumulative and non-cumulative CPI approaches) the cumulative CPI is the more stable approach, stabilizing from the 20% contract completion point, I hope I have eliminated some of the confusion among users of the CPI as to when to consider it stable.

I would like to thank Lt Col Thomas L. Bowman who provided the initial idea for this study and Wayne Abba who provided cost performance data from the Defense Acquisition Executive Summary (DAES) database. I would like to especially thank my faculty advisor, Major David S. Christensen, for the continuous guidance and support he provided. Most of all, I wish to thank my wife, Debra, and children, Kurtis and Bruce; for their patience and understanding while I wrote this thesis.

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Abstract

This study examines approaches currently used to determine when Cost Performance Index (CPI) stability occurs. The CPI indicates the cost performance efficiency of the work the contractor has accomplished to date; however it has value as a predictor of future contractor cost performance given that the CPI can be declared stable. Knowing that the CPI is stable allows government personnel to project the final cost of the contract and, if a cost overrun is projected, to determine the likelihood that the contractor can recover.

The range method was used to test for stability of cumulative and non-cumulative (three month, six month, and six month moving average) CPI values. The method measured the range of the CPI values that occurred after the 50 percent contract completion point. The results (range method sensitivity analysis) indicated that the cumulative CPI is more stable than the other CPIs examined, stabilizing from the 20 percent completion point. As a caveat however, the method of least squares showed that the cumulative CPI does tend to decline within the allowable range limit as the contract proceeds. Thus the final cumulative CPI value can be expected to be lower than the cumulative CPI value observed at the 20 percent contract completion point.

A REVIEW OF COST PERFORMANCE INDEX STABILITY

I. Introduction

General Issue

The Cost Performance Index (CPI) is used in the analysis of Cost Performance Report (CPR) data to determine the cost efficiency of the work the contractor has accomplished to date (11:267). Its value as an indicator of future contractor cost efficiency is dependent upon when the CPI can be declared stable (3; 5:82FF; 17:66). This causes some confusion because different approaches exist for determining when CPI stability occurs (13). A heuristic used by a practicing cost manager is "six months after contract award" (13). A more widely held belief is "that once a contractor has finished 50% of the contractual effort, his efficiency in the future will usually not vary more than $\pm 10\%$ from that achieved in the past" (5:82FF). Office of the Under Secretary of Defense (Acquisition) analysts have observed that "the cumulative CPI does not significantly improve during the period between 15% and 85% of contract performance; in fact, it tends to decline" (2:6). An empirical study suggests the CPI stabilizes at the 20% contract completion point (14:30).

Knowing that the CPI is stable has many benefits. Perhaps the greatest benefit is the ability to identify potential cost overruns before they occur (10:1; 12:27). A

recent example of this benefit was the early identification of a potential \$1 billion cost overrun on the Navy's A-12 program (2:6-7; 6:2). Other benefits include the ability to objectively evaluate the contractor's internal management system, planning process, performance (against the plan), and potential for recovering from a cost overrun (12:27).

Given the benefits of knowing when the CPI is stable, the objective of this study is to alleviate the confusion in determining CPI stability. This study will address the issue of a cumulative CPI naturally stabilizing because it is a cumulative index (4) and, in order to further investigate this issue, empirically evaluate currently used heuristics using both a cumulative and a non-cumulative CPI approach.

Research Problem

The problem is to determine if the CPI stabilizes for defense programs using cumulative, three month, six month and six month moving average CPI values.

Hypothesis. For each of these CPI approaches, the hypothesis to be tested is: the CPI is stable when a program is greater than 50 percent complete. Stability is declared when the CPI does not vary more than plus or minus 10 percent (5:82FF). Percent complete is the ratio "of the amount of work accomplished to date to the amount of work planned for the total contract" (8:12).

Scope of Research

The Defense Acquisition Executive Summary (DAES) database will be used to test the hypotheses. This database consists of quarterly cost and schedule performance reports which were prepared by program managers (2:3).

The DAES database provides for a comprehensive study of CPI stability. The database contains a variety of programs (satellites, ships, helicopters, planes, tanks, missiles, support equipment, ground electronics, avionics, software, engines, etc.) from the Army, Navy, and Air Force. A wide variety of phases are also represented: Demonstration/Validation (DEM/VAL), Full Scale Development (FSD), Low Rate Initial Production (LRIP), and Full Rate Production (FRP). Other efforts, such as Follow On Development (FOD) and Construction (Const) (for Navy ships) are also included. Contract types include Firm Fixed Price (FFP), Fixed Price Incentive Fee (FPIF), Cost Reimbursement (CR), Cost Plus Fixed Fee (CPFF), Cost Plus Incentive Fee (CPIF), and Cost Plus Award Fee (CPAF).

Limitations and Assumptions

For the purpose of this study, there are two substantial limitations with the DAES database. The first, a significant amount of data is missing. This impacts this study as, in order to best examine the hypotheses, programs containing (as a minimum) data representing the 20 through 85 percent complete interval must be used. However, with

several hundred programs in the database, there is still a large number of programs that qualify. The second limitation of this database, considering the intent of this study, is that the data are not consistently reported quarterly. In some cases, two, four, or even five month intervals must be used to represent quarterly contractor cost performance.

Background

Previous approaches used to determine CPI stability include heuristics and an empirical study. There are problems with each of these approaches however, which cause confusion for users of CPR data trying to determine when to declare the CPI stable.

The problem with heuristics is that there is a large number of them, each lacking statistical evidence. One cost manager uses "six months after contract award" as his heuristic (13), while a more popular heuristic when the "contractor has finished 50% of the contractual effort" (5:82FF). Yet another heuristic, based on observations by Office of the Under Secretary of Defense (Acquisition) analysts, suggests the CPI stabilizes when the contract is 15% complete (2:6).

An empirical study suggests the CPI stabilizes when the contract is 20% complete (14:30). The results of this study are limited however, because only 26 aircraft contracts

managed at Aeronautical Systems Division were examined and only cumulative CPI values were investigated.

This study provides additional knowledge on CPI stability because it reviews the results of the previous empirical study and statistically evaluates the currently used heuristics using cumulative and non-cumulative CPI values. In addition, because the DAES database is used for the analysis, the results of this study are applicable throughout the Department of Defense (DOD). The DAES database is the standard cost performance reporting database for all Services (1). It contains cost performance reporting information on a wide variety of contract types, program phases, and weapon systems from each of the different Services.

Before beginning with the review of the previous study and the statistical analysis of currently used heuristics however, a review of cost performance reporting and analysis terminology is necessary. The next chapter begins with such a review.

II. Literature Review

Cost Performance Reporting

The origin of defense oriented cost performance reporting systems can be traced to an Air Force measurement system implemented in 1960, called "PERT Cost". It was the first system to break down the entire contractual effort into small, individually manageable "work packages". In 1963, a new measurement system called "Earned Value" was applied to the Minuteman program. This system introduced the concept of evaluating contractor performance to date. The next attempt to improve the performance measurement system began in 1964 with the test of the "Cost Accomplishment" system. The newest feature of this system was the requirement to establish a firm baseline against which performance could be measured. In July of 1966, Air Force Systems Command (AFSC) provided written direction establishing the use of a standardized cost performance measurement approach for all AFSC major weapon system acquisition programs. The directive was known as the "Cost/Schedule Planning and Control Specification (C/SPCS)". Less than a year later, in December of 1967, the Department of Defense adopted the Air Force's performance measurement approach and renamed it "Cost/Schedule Control Systems Criteria (C/SCSC)". (16:21)

The intent of the C/SCSC established in 1967 is still valid today, to require major weapon system contractors to establish effective internal management control systems (7:v). It is important to note that C/SCSC are not a cost or schedule performance measurement system, but a set of criteria that the contractors' internal management control systems must meet (7:v). In general, the C/SCSC require the contractor to: define (in detail) the contractual work required, identify who the work is assigned to within the organization, prepare budgets and schedules, and periodically identify variances from planned performance (16:22). The C/SCSC do not require the contractor to externally report the information contained within the internal control system (7:vi). Data from the contractor's internal management control systems will only be provided to the government if the contract requires the submission of a CPR or Cost/Schedule Status Report (C/SSR), as specified by the Contract Data Requirements List (CDRL) (7:vi-viii). The CPR is used when the contract requires C/SCSC compliance; the C/SSR is used when C/SCSC compliance is not considered necessary (7:vi-viii).

Although a variety of information can be specified by the CDRL, most important to cost performance reporting analysis is the following set of data elements:

Actual Cost of Work Performed (ACWP). The costs actually incurred and recorded in accomplishing the work performed within a given time period. (7:2-1)

Budget at Completion (BAC). Contract Budget Base less Management Reserve. (8:12)

Budgeted Cost for Work Performed (BCWP). The sum of the budgets for completed work packages and completed portions of open work packages, plus the applicable portion of the budgets for level of effort and apportioned effort. (7:2-2)

Budgeted Cost for Work Scheduled (BCWS). The sum of the budgets for all work packages, planning packages, etc., scheduled to be accomplished (including in-process work packages), plus the amount of level of effort and apportioned effort scheduled to be accomplished within a given time period. (7:2-2)

Contract Budget Base (CBB). The negotiated contract cost plus the estimated cost of authorized unpriced work. (7:2-2)

Estimate at Completion (EAC)¹. Actual direct costs, plus indirect costs allocable to the contract, plus the estimate of costs (direct and indirect) for authorized work remaining. (7:2-2)

Management Reserve (MR). An amount of the total allocated budget withheld for management control purposes rather than designated for the accomplishment of a specific task or set of tasks. It is not a part of the Performance Measurement Baseline. (7:2-2)

CPR Analysis

CPR analysis is essential for managers within the contractor's organization. Analysis of variances among CPR data elements enable managers to determine program cost and schedule progress by specific work element. As such, the identity and magnitude of specific sources of cost and schedule overruns can be identified so that the appropriate corrective action can be taken. Furthermore, the past data provide a basis for projecting future performance. A

¹ Latest Revised Estimate (LRE) is a synonym for EAC.

possible additional use of the data could be for evaluation of the performance of the organizational unit assigned the work element. (16:22)

Government managers and decision makers at all levels use the results from CPR analysis of summary CPR data to evaluate contractor performance (15:12). First of all, the results of the analysis can be used to determine if the contractor's cost and schedule management control system is "functioning properly" (14:7). If the CPR is submitted in a timely and auditable manner, reasonably allocates the budget to each work element, and accurately reports work progress (10:3; 12:27), government personnel can place confidence in the contractor's management control system (12:27). As a result, DOD managers, analysts, and decision makers can be confident that the CPR data and analytical results are reliable (10:3; 14:7). Given that the CPR data are reliable, the CPR analysis can be used to assess how well the contractor planned the work and how well the contractor is proceeding according to the plan (12:27; 15:12). Cost/schedule overruns or underruns indicate deficiencies in the plan and/or in the contractor's ability to obtain/manage resources (15:12); thus the government manager can use the CPR analysis to judge the reasonability of the contractor's progress payment request (2:6).

Perhaps the government's most valuable uses of CPR analytical methods are to identify potential cost and schedule performance problems, and subsequently, to

determine the likelihood that the contractor can recover (2:5-6; 12:27). The Navy's A-12 program is a recent example which demonstrates the value of this analytical capability. In October of 1989, the DOD Comptroller staff's analysis of cost performance data indicated the A-12 program would be "two years behind schedule and would likely overrun the Full Scale Development contract ceiling by \$500 million" (2:21). In March of 1990, Gary Christle, the Under Secretary for Defense (Acquisition)'s Deputy Director for Cost Management, analyzed the CPR data and estimated that by completion of the development contract, the A-12 program "would be at least \$1.0 billion over ceiling and at least one year behind schedule" (6:2). Despite these findings, the contractor team continued to provide general assurances that the A-12 development contract "would be completed within ceiling cost" (6:4) and with only a three month slip in the scheduled first flight (2:25). The projections based on the analysis of CPR data from the DAES database proved true however:

On 1 June 1990, the contractor team advised the Navy of a significant additional slip in the schedule for first flight [and] that the Full Scale Development effort would overrun the contract ceiling by an amount which the contractor team could not absorb. (2:1)

Indicators Used in CPR Analysis

There are a number of indicators used in CPR analysis, but only three of these indicators are used in this study: the Schedule Performance Index (SPI), the To Complete

Performance Index (TCPI), and the focus of this study, the Cost Performance Index (CPI).

The SPI "is an indication of the schedule efficiency with which work has been accomplished" (8:14) and can be calculated using cumulative or non-cumulative data:

$$SPI = BCWP / BCWS \quad (1)$$

For example, if the BCWP = \$80,000 and the BCWS = \$100,000, then the SPI = .800. This means that only 80 percent of the work scheduled to have been completed has actually been completed, thus the contractor is behind schedule. Conversely, if the index is greater than 1.0, the SPI indicates that the contractor is performing ahead of schedule. An index of 1.0 indicates the contractor is performing on schedule. (8:14)

The CPI "is an indication of the cost efficiency with which work has been accomplished" (8:14) and can be calculated using cumulative or non-cumulative data:

$$CPI = BCWP / ACWP \quad (2)$$

For example, if the BCWP = \$80,000 and the ACWP = \$90,000, then the CPI = .888. This means that approximately 89 cents of value was received for each budget dollar the contractor spent, thus the contractor is experiencing a cost overrun. A CPI greater than 1.0 indicates that the contractor is experiencing a cost underrun while an index of 1.0 indicates the contractor is on budget. (8:13-14)

The TCPI is the CPI that the contractor must achieve for the remainder of the contract to complete the contract on budget:

$$TCPI = (BAC - BCWP) / (BAC - ACWP) \quad (3)$$

Using the numbers from the CPI example and a BAC = \$190,000, the TCPI = 1.10. This means that if the contractor's CPI is less than 1.10 for the remainder of the contract, the contract will end with a cost overrun. (8:14-15)

Importance of a Stable CPI

Knowing that the CPI is stable has many benefits. First of all, it indicates that the contractor's work planning, task budgeting, and cost reporting systems are in synch (14:10), giving government personnel confidence in the contractor's cost management control system (10:3). In addition, a stable CPI indicates how well the contractor planned the work and/or how well the contractor is proceeding according to the plan (14:10).

Perhaps the government's most valuable uses of a stable CPI are to project the final cost of the contract, and subsequently, if a cost overrun is projected, to determine the likelihood that the contractor can recover (12:27). A number of different formulas have been developed to project the final cost of the contract or Estimate at Completion (EAC) (10:7). Most of these formulas are sensitive to small changes in the CPI value however, therefore it is very

important that the CPI used in determining the EAC is stable and accurately reflects the contractor's cost performance (14:10). If a cost overrun is projected, the TCPI, in conjunction with the stable CPI, can be used to determine the likelihood that the contractor can recover (8:14-15). For example, if the required TCPI is 1.10 and the CPI is determined stable at .90, government personnel can declare with confidence that the contract will end with a cost overrun because the contractor cannot achieve a CPI of 1.10 (8:14-15; 14:11).

Faults With Previous CPI Stability Approaches

Previous approaches used to determine CPI stability include heuristics and an empirical study. Each of these approaches have weaknesses however, which questions their value as viable approaches to use to determine when to declare the CPI stable.

The predominant problems with the heuristics are that they are large in number, they often contradict one another, and none of them are backed by statistical evidence. One cost manager uses "six months after contract award" (13), while a more common heuristic is when the "contractor has finished 50% of the contractual effort" (5:82FF). Another heuristic suggests the CPI stabilizes when the contract is 15% complete (2:6).

The empirical study suggests the cumulative CPI stabilizes when the contract is 20% complete (14:30). There

are two weaknesses with this study however. First, it was very limited in scope; only 26 contracts from seven different aircraft programs managed at Aeronautical Systems Division were examined (14:13). Second, only cumulative CPI values were investigated; a cumulative CPI naturally stabilizes because it is a cumulative index (4).

Figure 1 and Figure 2 illustrate this tendency. The values used to generate the plots in Figure 1 are located in Tables 1 and 2. The values used to generate the plots in Figure 2 are located in Tables 3 and 4. In each figure, the percent complete is plotted on the x axis and the CPI required for the remainder of the contract in order to affect a 10% change in the current cumulative CPI is plotted on the y axis. For example, for the bottom line in Figure 1, given that the current cumulative CPI is .8 at the 10% complete point, a CPI of .712 is required for the remaining 90% of the contract to cause a 10% decrease in the cumulative CPI. At the 20% complete point, a CPI of .702 is required for the remainder of the contract to reduce the cumulative CPI from .8 to .72. The plot of the bottom line continues by repeating this calculation at successive 10% intervals. Note that the plot of the required CPIs decreases exponentially as the contract proceeds. In fact, at the 90% complete point, a CPI of .379 is required for the remaining period in order to reduce the cumulative CPI from .8 to .72.

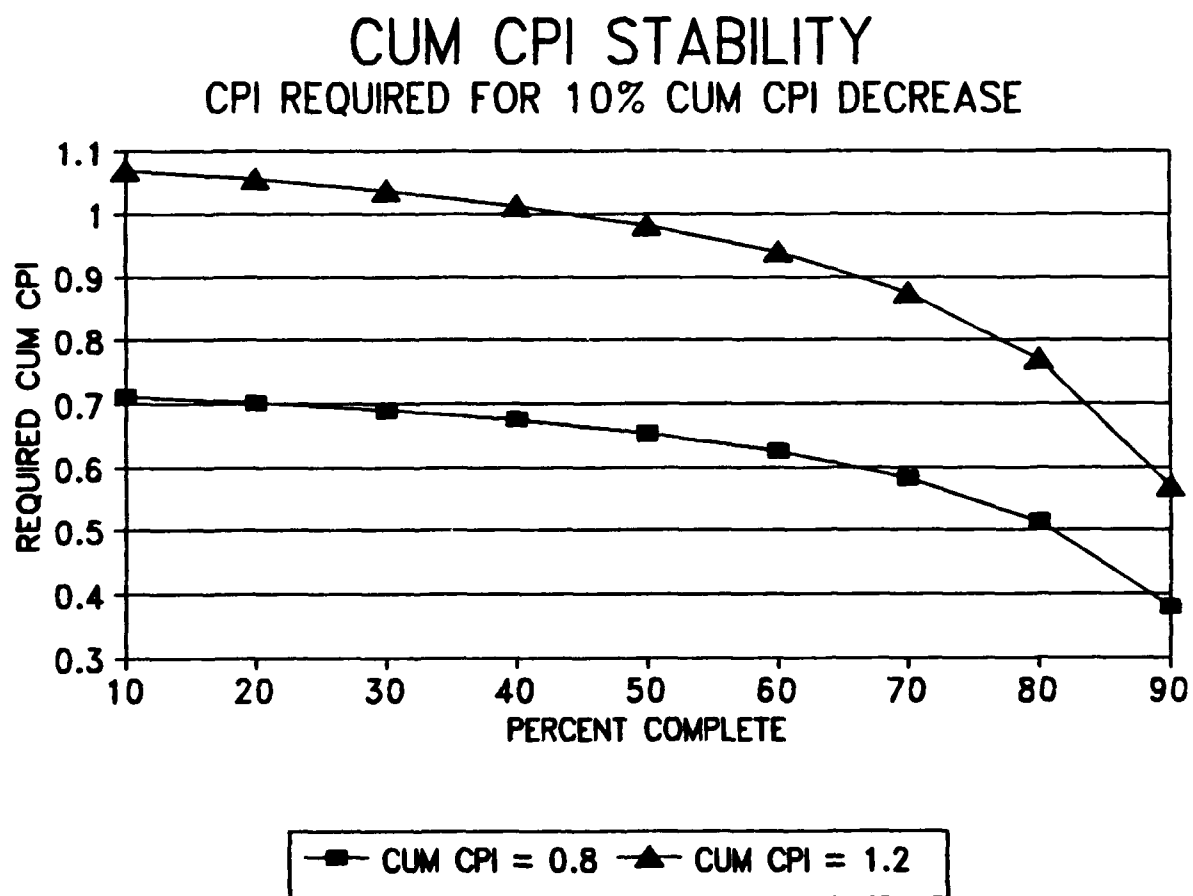


Figure 1. Exponentially Decreasing Required CPI

Table 1

Required Cumulative CPI Values To Cause A 10% Decrease
(BAC is 100 and the Current Cumulative CPI is .8)

Percent Complete	Cumulative BCWP	Cumulative ACWP	Required CPI _{cum}
10	10.00	12.50	0.712
20	20.00	25.00	0.702
30	30.00	37.50	0.690
40	40.00	50.00	0.675
50	50.00	62.50	0.655
60	60.00	75.00	0.626
70	70.00	87.50	0.584
80	80.00	100.00	0.514
90	90.00	112.50	0.379

Table 2

Required Cumulative CPI Values To Cause A 10% Decrease
(BAC is 100 and the Current Cumulative CPI is 1.2)

Percent Complete	Cumulative BCWP	Cumulative ACWP	Required CPI _{cum}
10	10.00	8.33	1.068
20	20.00	16.67	1.054
30	30.00	25.00	1.036
40	40.00	33.33	1.013
50	50.00	41.67	0.982
60	60.00	50.00	0.939
70	70.00	58.33	0.876
80	80.00	66.67	0.771
90	90.00	75.00	0.568

CUM CPI STABILITY

CPI REQUIRED FOR 10% CUM CPI INCREASE

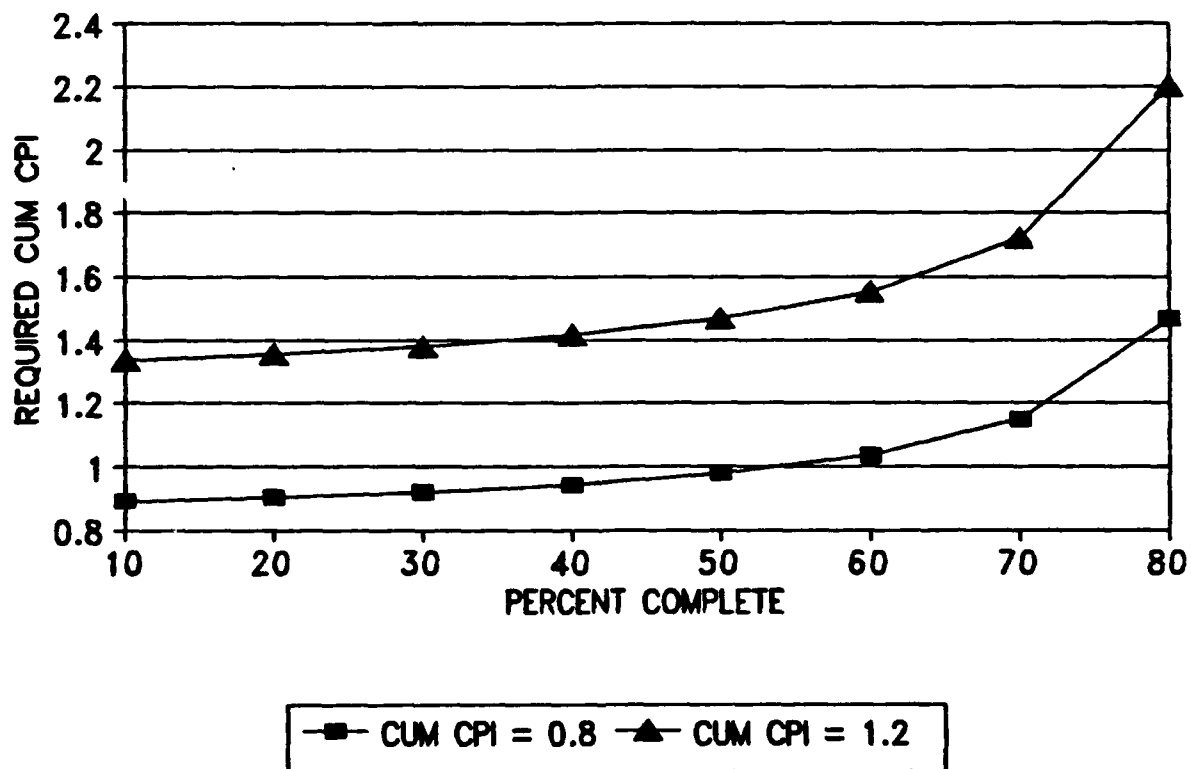


Figure 2. Exponentially Increasing Required CPI

Table 3

Required Cumulative CPI Values To Cause A 10% Increase
(BAC is 100 and the Current Cumulative CPI is .8)

Percent Complete	Cumulative BCWP	Cumulative ACWP	Required CPI _{cum}
10	10.00	12.50	0.890
20	20.00	25.00	0.903
30	30.00	37.50	0.919
40	40.00	50.00	0.943
50	50.00	62.50	0.978
60	60.00	75.00	1.035
70	70.00	87.50	1.148
80	80.00	100.00	1.467
90	90.00	112.50	8.800

Table 4

Required Cumulative CPI Values To Cause A 10% Increase
(BAC is 100 and the Current Cumulative CPI is 1.2)

Percent Complete	Cumulative BCWP	Cumulative ACWP	Required CPI _{cum}
10	10.00	8.33	1.335
20	20.00	16.67	1.354
30	30.00	25.00	1.379
40	40.00	33.33	1.414
50	50.00	41.67	1.467
60	60.00	50.00	1.553
70	70.00	58.33	1.722
80	80.00	66.67	2.200
90	90.00	75.00	13.200

The same approach is taken for constructing the other plot in Figure 1 and the plots of Figure 2. In Figure 2 however, a 10% increase in the cumulative CPI is investigated. In any case, as the contract proceeds, it takes an (exponentially) increasingly larger change in future cost performance from past cost performance to change the cumulative CPI by ten percent. Thus the cumulative CPI tends to stabilize naturally as the contract proceeds, because the weight of the past cost performance (exponentially) increasingly dampens the impact of any future cost performance.

The formula used to determine the required CPI is:

$$(BAC - BCWP) / \{ [BAC / (CPI_{cum} * (1 + PC))] - ACWP \} \quad (4)$$

This formula is a slightly modified version of the TCPI formula. Like the TCPI formula, cumulative values are used for the BCWP and ACWP. Unlike the TCPI formula, the BAC in the denominator is divided by the product of the current cumulative CPI and one plus the percent change (PC, expressed as a decimal) to be investigated. For example, referring to Table 4, given that the current cumulative CPI is 1.2, the BAC is 100, the BCWP is 10, the ACWP is 8.33, and the PC to be investigated is a 10% increase (.10), a cumulative CPI of 1.335 is required for the remainder of the contract in order to increase the current cumulative CPI by 10 percent.

The change to the TCPI formula was necessary so the result reflects the CPI required for the remainder of the contract needed to change the current cumulative CPI value by a given percentage. This differs from the original TCPI formula as it indicates the CPI that the contractor must achieve for the remainder of the contract to complete the contract on budget.

The Significance of This Study

This study provides additional knowledge on CPI stability because it overcomes the weaknesses of the previous approaches. First of all, both cumulative and non-cumulative (three month, six month, and six month moving average) CPI values will be statistically evaluated. In addition, the scope of this study is very broad, as the DAES database contains cost performance reporting information on a wide variety of contract types, program phases, and weapon systems from each of the different services. The following chapter discusses this study's analytical approach and the contents of the DAES database in greater detail.

III. Methodology

The Database

Data selected from the Defense Acquisition Executive Summary (DAES) database will be used to test the hypotheses of this study. The database was obtained from the Office of the Under Secretary of Defense (Acquisition) and contains cost performance data from June 1970 to February 1991.² The DAES database is the standard cost performance reporting database for all Services (1) and consists of quarterly cost and schedule performance reports which were prepared by program managers (2:3). Data elements selected from this database and used in this study include the cumulative BCWP, cumulative ACWP, MR, and CBB.³ Other information taken from the database includes the program name, contract subject, program phase, and contract type.

Contracts were chosen from the database based on the completeness of the data. Only contracts containing, as a minimum, data representing cost performance between the 20 and 85 percent complete points were selected. This specific percent complete range was selected to allow for a sensitivity analysis of the range method (discussed later in this chapter). Following this criterion, 155 contracts from

² The data used in this study are available from AFIT/LSY, Major David Christensen.

³ Reference definitions on pages 7 and 8.

44 different programs qualified for this study. As such, the DAES database provides for a comprehensive study of CPI stability. The qualifying contracts represent a variety of programs (airplanes, ammunition, avionics, engines, ground electronics, helicopters, missiles, rockets, satellites, software, submarines, support equipment, surface ships, tanks, test equipment, and torpedoes) from the Army, Navy, and Air Force. A wide variety of phases are also represented: Demonstration/Validation (DEM/VAL), Full Scale Development (FSD), Follow On Development (FOD), Low Rate Initial Production (LRIP), Full Rate Production (FRP) and Construction (Const) (for Navy ships). The variety of contract types represented include: Fixed Price Incentive Fee (FPIF), Cost Plus (CP), Cost Plus Fixed Fee (CPFF), Cost Plus Incentive Fee (CPIF), and Cost Plus Award Fee (CPAF). Appendix A includes a complete listing of each contract used in this study, by program name, contract subject, program phase, and contract type.

Method of Analysis

Hypotheses. For cumulative and non-cumulative (three month, six month, and six month moving average) CPI values, the hypothesis to be tested is: the CPI is stable when a program is greater than 50 percent complete.

CPI Calculations. The cumulative CPI calculations are determined by using the cumulative BCWP values and

cumulative ACWP values as reported in the DAES database.⁴

Non-cumulative CPI calculations are made as follows:

$$CPI = (BCWP_1 - BCWP_2) / (ACWP_1 - ACWP_2) \quad (5)$$

In each case, $BCWP_1$ and $ACWP_1$ represent current cumulative values. For the three month CPI calculations, $BCWP_2$ and $ACWP_2$ represent the cumulative values reported three months prior to the current cumulative values. For the six month and six month moving average calculations, $BCWP_2$ and $ACWP_2$ represent the cumulative values reported six months prior to the current cumulative values. The difference between the two six month calculations is that the moving average calculation is performed at three month, instead of six month intervals.

As was discussed earlier, there is a limitation with using the DAES database for this study. The data are not consistently reported quarterly. In some cases, two, four, or even five month intervals must be used to represent quarterly cost performance.

Percent Complete Calculations. Percent complete is the ratio "of the amount of work accomplished to date to the amount of work planned for the total contract" (8:12). In this study, the percent complete is determined by dividing the cumulative BCWP into the current BAC (CBB less MR):

$$PERCENT COMPLETE = BCWP / (CBB - MR) \quad (6)$$

⁴ Reference formula (2) on page 11.

Problems do occur with using this calculation when a substantial amount of new effort is added to the contract during the period under investigation. The percent complete actually declines even though the cumulative BCWP increases.

In the previous empirical study, the final BAC and monthly BAC were used to determine the percent complete (14:28). The study found that the number of contracts with stable CPIs was identical using both approaches (14:28). Given this, and that the number of contracts examined in this study would have to be substantially reduced since the final BAC is not identified in a large number of the contracts, calculating the percent complete by using the current BAC will be the only approach used. As an added note, this is the preferred approach. In practice it is not possible to determine CPI stability by using the final BAC; users of cost performance data do not know the final BAC until the contract is complete.

As a caveat, contracts which have an unstable baseline are identified in Appendix A. In this study, a contract baseline is defined as unstable when the percent complete decreases between any two consecutive cost performance periods.

Stability and the Range Method. The CPI is considered stable when the CPI does not vary more than plus or minus 10 percent (5:82FF). The range method will be used in this study to test for CPI stability. The range is the difference between the maximum and minimum CPI values

located in the percent complete interval of interest. If the range is less than or equal to .200, the CPI is considered stable. For the hypotheses, the interval of interest is between the 50 percent complete point and the final reported percent complete point.

If the results of the range method show that a CPI is stable from the 50 percent complete point, a sensitivity analysis will be conducted on that particular CPI approach (cumulative or non-cumulative) by testing for CPI stability from the 40, 30, 20, 10, and 0 percent complete points. In addition to the sensitivity analysis, a confidence interval for the mean of the ranges will also be calculated.

Confidence Interval for the Mean of the Ranges. The large sample method will be used, based on the assumption that this method is appropriate when the number of samples (contracts analyzed) is greater than thirty, to determine confidence intervals for the sample ranges. The confidence interval (CI) is calculated as follows:

$$CI = x_{bar} \pm [(z_{\alpha/2})(s / n^{\frac{1}{2}})] \quad (7)$$

where

x_{bar} = the sample mean

$z_{\alpha/2}$ = the two-tail z critical value

s = the sample standard deviation

n = the sample size

The level of confidence for the confidence interval indicates the number of times out of 100 that computed

confidence intervals are expected to contain the true mean (in this study, the true mean of the ranges). (9:254,260)

Correlation With Contract Characteristics. This method will examine the relationship between CPI stability and contract characteristics. The 155 contracts are divided into 26 groups by using various combinations of fixed price (FP), cost plus (CP), production (P), development (D), stable baseline (S), and unstable baseline (U) contract characteristics. Production contracts include those contracts in full rate production, low rate initial production, and construction. Development contracts include those contracts in full scale development, follow on development, and demonstration/validation. The number of contracts possessing a certain set of characteristics are determined, then the percentage of these contracts that have stable CPIs are calculated.

Method of Least Squares. The method of least squares will be used to identify trends in cost performance. This is done because the range method only investigates the variance. Considering that the allowable index range is .200, a downward or upward trend is certainly possible.

The method of least squares consists of finding the line that minimizes the sum of squared vertical deviations between the estimated line and the plotted points (18:9-10). In this study, the slope (S) and the intercept (I) represent the estimators used to describe the best fitting line. The

slope is the focus of this study however, as it indicates the direction and magnitude of the cost performance trend.

The equations used to estimate the slope and intercept are:

$$S = [n\sum x_i y_i - (\sum x_i)(\sum y_i)] / [n\sum x_i^2 - (\sum x_i)^2] \quad (8)$$

and

$$I = (\sum y_i - S\sum x_i) / n \quad (9)$$

where

n = the number of cost performance periods investigated

x = the percent complete

y = the CPI value for the period investigated

Once the estimators are calculated, the estimated line,

$I + Sx_i$, is plotted to see if it fits the CPI data.

(18:8-10)

Justification of Approach

The range method and the method of least squares are the most appropriate methods for testing the hypotheses. These methods not only investigate the variance of the CPI values, but investigate trends in the contractor's cost performance.

The interval method was also considered as an alternative approach to investigating the stability of the non-cumulative CPI values. This method consists of determining the +/- 10 percent interval around the CPI value located at the 50 percent complete point, then determining

if all subsequent CPI values fall within the established interval. If so, the CPI is declared stable. The problem with this method however, is that it places too much emphasis on the CPI value that occurs at the 50 percent complete point (14:19-20). This is especially true when investigating the stability of non-cumulative CPI values. The contractor's cost performance during the three month period which includes the 50 percent complete point may be one of the highest or lowest CPI values, thus the interval would be set around one of the extreme values and not a centered value. The result would be that the interval method finds the CPI unstable, whereas the range method, the more appropriate measure of variance, finds it stable.

Given the risk of placing too much emphasis on the CPI value that occurs at the 50 percent complete point, this study will only use the range method to test CPI stability. The next chapter presents the results of this method and the method of least squares.

IV. Results

Non-cumulative CPI Values

Range Method. The results of the range method calculations for the three month, six month, and six month moving average non-cumulative CPI values are listed in Appendix B. The range values indicate the difference between the maximum and minimum CPI values observed after the 50 percent contract completion point. A summary of the results are provided in Table 5. The table includes the number of contracts with stable CPIs (range less than 0.201), the percentage of total contracts with stable CPIs (155 total contracts in the study), the maximum range, the minimum range, the mean range, and the range standard deviation.

Table 5

Summary of the Non-cumulative CPI Results

	Three Month	Six Month	Six Month Moving Average
Number of Stable Contracts	10	50	29
Percentage of Total Contracts	6%	32%	19%
Maximum Range Observed	17.738	4.615	4.651
Minimum Range Observed	0.073	0.001	0.036
Mean of the Ranges	1.072	0.419	0.530
Standard Deviation	1.740	0.519	0.545

Correlation With Contract Characteristics. The next table, Table 6, examines the relationship between non-cumulative CPI stability and contract characteristics. The 155 contracts have been divided into 26 groups by using various combinations of fixed price (FP), cost plus (CP), production (P), development (D), stable baseline (S), and unstable baseline (U) contract characteristics. For example, in the table, "FP/P" represents the contracts that are fixed price and in the full rate production, initial production, or construction phase.

Listed next to the contract characteristics column is the column identifying the number of contracts in the study that possess the stated characteristics. For example, there are 101 fixed price contracts (FP) in this study, of those, 75 are in a production phase (FP/P) and 26 are in a development phase (FP/D). Of the 75 that are fixed price and in a production phase (FP/P), 61 have stable baselines (FP/P/S) and 14 have unstable baselines (FP/P/U).

The remaining three columns list the number of contracts that have stable three month, six month, or six month moving average CPIs as a percentage of all contracts possessing the stated set of contract characteristics. For instance, 8% of the 101 fixed price contracts have stable three month CPIs after the 50% contract completion point, 36% of the 101 fixed price contracts have stable six month CPIs after the 50% completion point, and 23% of the 101

fixed price contracts have stable six month moving average
CPIs after the 50% completion point.

Table 6

Non-cumulative CPI Stability
Relationship To Contract Characteristics

Characteristics/ Number of Contracts	Three Month	Six Month	Six Month Moving Average	
FP	101	8%	36%	23%
CP	54	4%	26%	11%
P	93	5%	39%	23%
D	62	8%	23%	13%
S	109	8%	39%	24%
U	46	2%	15%	7%
FP/P	75	7%	39%	25%
FP/D	26	12%	27%	15%
FP/S	76	11%	43%	28%
FP/U	25	0%	12%	8%
CP/P	18	0%	39%	11%
CP/D	36	6%	19%	11%
CP/S	33	3%	30%	15%
CP/U	21	5%	19%	5%
P/S	75	7%	43%	25%
P/U	18	0%	22%	11%
D/S	34	12%	32%	21%
D/U	28	4%	11%	4%
FP/P/S	61	8%	43%	28%
FP/P/U	14	0%	21%	14%
FP/D/S	15	20%	47%	27%
FP/D/U	11	0%	0%	0%
CP/P/S	14	0%	43%	14%
CP/P/U	4	0%	25%	0%
CP/D/S	19	5%	21%	16%
CP/D/U	17	6%	18%	6%

FP Fixed price
CP Cost plus
P Production
D Development
S Stable baseline
U Unstable baseline

Cumulative CPI Values

Range Method. The results of the range method calculations for the cumulative CPI values are listed in Appendix C. The range values indicate the difference between the maximum and minimum CPI values observed from the 0, 10, 20, 30, 40 and 50 percent contract completion points. A summary of the results are provided in Table 7. The table lists the total number of contracts analyzed, the number of those contracts that have stable CPIs (range less than 0.201), the associated percentage of total contracts, the maximum range, the minimum range, the mean range, and the range standard deviation.

Table 7

Summary of the Range Method Cumulative CPI Results

	<u>Percent Complete</u>					
	0%	10%	20%	30%	40%	50%
Number of Contracts	110	152	155	155	155	155
Number Stable	59	116	134	141	150	153
Percent Stable	54%	76%	86%	91%	97%	99%
Maximum Range	1.243	0.644	0.434	0.364	0.312	0.299
Minimum Range	0.017	0.017	0.017	0.007	0.003	0.003
Mean of the Ranges	0.262	0.145	0.115	0.096	0.081	0.069
Standard Deviation	0.213	0.103	0.078	0.068	0.056	0.051

Confidence Interval for the Mean of the Ranges. The results of the confidence interval calculations for the mean of the ranges are presented in Tables 8 through 10. The 90% confidence interval is examined in Table 8; and to show how the size of the interval diminishes as a contract progresses, illustrated in Figure 3. The 95% and 99% confidence intervals are examined in Table 9 and Table 10 respectively. The tables include the sample size (the number of contracts analyzed), the sample mean of the ranges, the sample range standard deviation, the two-tail z critical value, the calculated upper limit, and calculated lower limit.

The confidence interval can be viewed in two different ways. For example, consider the results for the 0% completion point in Table 8. The 90% confidence interval for the mean of the cumulative CPI range can be viewed as from 0.229 to 0.295 or as 0.262 ± 0.033 .

Table 8
Mean of the Ranges 90% Confidence Interval

	0%	10%	<u>Percent Complete</u>			
			20%	30%	40%	50%
Sample Size	110	152	155	155	155	155
Sample Mean	0.262	0.145	0.115	0.096	0.081	0.069
Standard Deviation	0.213	0.103	0.078	0.068	0.056	0.051
Z Critical Value	1.645	1.645	1.645	1.645	1.645	1.645
Upper Limit	0.295	0.159	0.125	0.105	0.088	0.076
Lower Limit	0.229	0.131	0.105	0.087	0.074	0.062

90% CONFIDENCE INTERVAL FOR THE MEAN OF THE RANGES

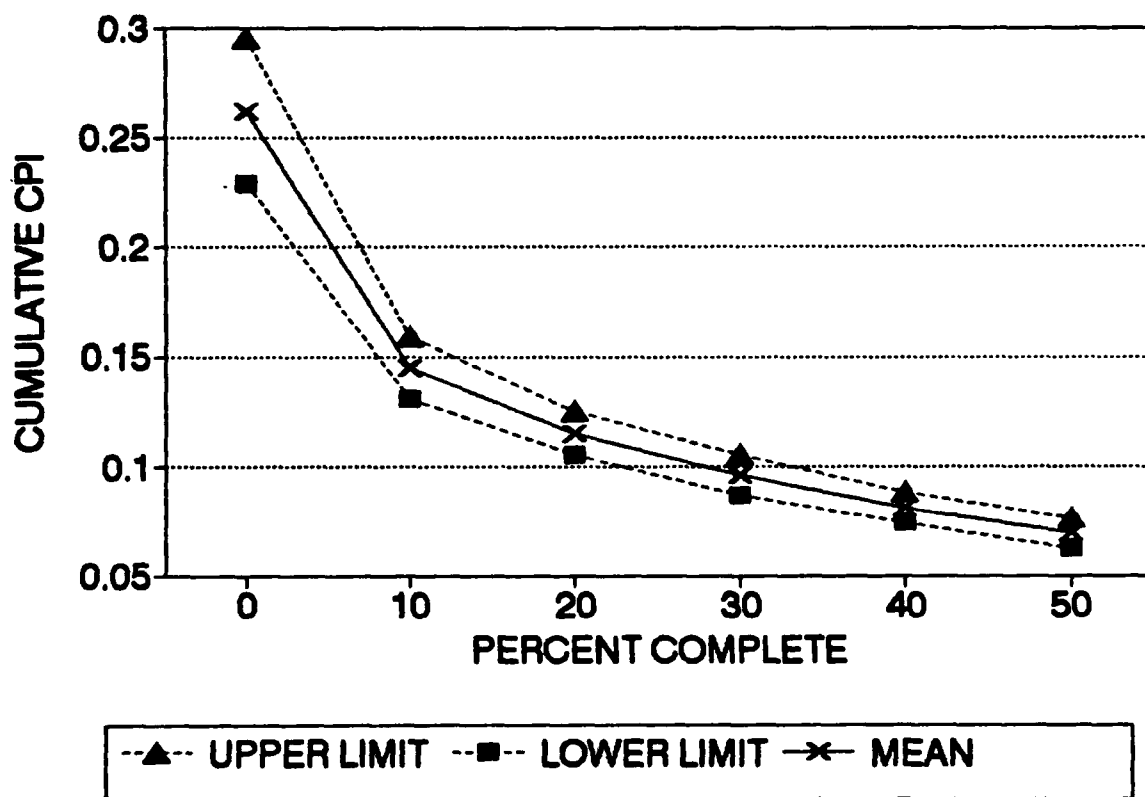


Figure 3. Mean of the Ranges 90% Confidence Interval

Table 9
Mean of the Ranges 95% Confidence Interval

	0%	10%	<u>Percent Complete</u>			
			20%	30%	40%	50%
Sample Size	110	152	155	155	155	155
Sample Mean	0.262	0.145	0.115	0.096	0.081	0.069
Standard Deviation	0.213	0.103	0.078	0.068	0.056	0.051
Z Critical Value	1.960	1.960	1.960	1.960	1.960	1.960
Upper Limit	0.302	0.161	0.127	0.107	0.090	0.077
Lower Limit	0.222	0.129	0.103	0.085	0.072	0.061

Table 10
Mean of the Ranges 99% Confidence Interval

	0%	10%	<u>Percent Complete</u>			
			20%	30%	40%	50%
Sample Size	110	152	155	155	155	155
Sample Mean	0.262	0.145	0.115	0.096	0.081	0.069
Standard Deviation	0.213	0.103	0.078	0.068	0.056	0.051
Z Critical Value	2.575	2.575	2.575	2.575	2.575	2.575
Upper Limit	0.314	0.167	0.131	0.110	0.093	0.080
Lower Limit	0.210	0.123	0.099	0.082	0.069	0.058

Correlation With Contract Characteristics. The results of the study of the relationship between cumulative CPI stability and contract characteristics is presented in Tables 11 through 16. Like Table 6, the contracts have been divided into 26 groups by using various combinations of fixed price (FP), cost plus (CP), production (P), development (D), stable baseline (S), and unstable baseline (U) contract characteristics. The 26 different combinations are listed in the first column. The second column identifies the number of contracts in the study that possess the stated characteristics. The remaining two columns report those contracts that have stable cumulative CPIs as a number and as a percentage of all contracts possessing the given characteristics. For instance, in Table 11, there are 76 fixed price contracts that have CPR data available from the contract start, of those, 42 (or 55%) of them have stable cumulative CPIs from the 0% completion point.

An alternate perspective is presented in Table 17. The first two columns identify the mix of contract characteristics and the associated number of them represented in this study. The third and fourth columns indicate the maximum and minimum cumulative CPI stabilization points observed for contracts possessing the stated characteristics. The last two columns identify the mean and standard deviation of the stabilization points observed. For example, of the 101 fixed price contracts studied, the maximum observed stabilization point is 70%

complete and the minimum is 0% complete, the mean stabilization point is 11% complete with a 14% standard deviation.

Table 11
Relationship From the 0% Completion Point

Characteristics/ Number of Contracts		Number With Stable CPIs	Percentage
FP	76	42	55%
CP	34	17	50%
P	71	41	58%
D	39	18	46%
S	78	44	56%
U	32	15	47%
FP/P	60	34	57%
FP/D	16	8	50%
FP/S	59	33	56%
FP/U	17	9	53%
CP/P	11	7	64%
CP/D	23	10	43%
CP/S	19	11	58%
CP/U	15	6	40%
P/S	60	36	60%
P/U	11	5	45%
D/S	18	8	44%
D/U	21	10	48%
FP/P/S	52	30	58%
FP/P/U	8	4	50%
FP/D/S	7	3	43%
FP/D/U	9	5	56%
CP/P/S	8	6	75%
CP/P/U	3	1	33%
CP/D/S	11	5	45%
CP/D/U	12	5	42%

FP Fixed price
 CP Cost plus
 P Production
 D Development
 S Stable baseline
 U Unstable baseline

Table 12

Relationship From the 10% Completion Point

Characteristics/ Number of Contracts	Number With Stable CPIs	Percentage
FP	100	74%
CP	52	81%
P	92	80%
D	60	70%
S	109	81%
U	43	65%
FP/P	74	76%
FP/D	26	69%
FP/S	76	75%
FP/U	24	71%
CP/P	18	100%
CP/D	34	71%
CP/S	33	94%
CP/U	19	58%
P/S	75	79%
P/U	17	88%
D/S	34	85%
D/U	26	50%
FP/P/S	61	74%
FP/P/U	13	85%
FP/D/S	15	80%
FP/D/U	11	55%
CP/P/S	14	100%
CP/P/U	4	100%
CP/D/S	19	89%
CP/D/U	15	47%

FP Fixed price
 CP Cost plus
 P Production
 D Development
 S Stable baseline
 U Unstable baseline

Table 13

Relationship From the 20% Completion Point

Characteristics/ Number of Contracts		Number With Stable CPIs	Percentage
FP	101	88	87%
CP	54	46	85%
P	93	84	90%
D	62	50	81%
S	109	99	91%
U	46	35	76%
FP/P	75	66	88%
FP/D	26	22	85%
FP/S	76	66	87%
FP/U	25	22	88%
CP/P	18	18	100%
CP/D	36	28	78%
CP/S	33	33	100%
CP/U	21	13	62%
P/S	75	67	89%
P/U	18	17	94%
D/S	34	32	94%
D/U	28	18	64%
FP/P/S	61	53	87%
FP/P/U	14	13	93%
FP/D/S	15	13	87%
FP/D/U	11	9	82%
CP/P/S	14	14	100%
CP/P/U	4	4	100%
CP/D/S	19	19	100%
CP/D/U	17	9	53%

FP Fixed price
 CP Cost plus
 P Production
 D Development
 S Stable baseline
 U Unstable baseline

Table 14

Relationship From the 30% Completion Point

Characteristics/ Number of Contracts	Number With Stable CPIs	Percentage
FP	101	94
CP	54	47
P	93	88
D	62	53
S	109	103
U	46	38
FP/P	75	70
FP/D	26	24
FP/S	76	70
FP/U	25	24
CP/P	18	18
CP/D	36	29
CP/S	33	33
CP/U	21	14
P/S	75	70
P/U	18	18
D/S	34	33
D/U	28	20
FP/P/S	61	56
FP/P/U	14	14
FP/D/S	15	14
FP/D/U	11	10
CP/P/S	14	14
CP/P/U	4	4
CP/D/S	19	19
CP/D/U	17	10

FP Fixed price
 CP Cost plus
 P Production
 D Development
 S Stable baseline
 U Unstable baseline

Table 15
Relationship From the 40% Completion Point

Characteristics/ Number of Contracts	Number With Stable CPIs	Percentage
FP	101	98%
CP	54	52%
P	93	92%
D	62	58%
S	109	107%
U	46	43%
FP/P	75	74%
FP/D	26	24%
FP/S	76	74%
FP/U	25	24%
CP/P	18	18%
CP/D	36	34%
CP/S	33	33%
CP/U	21	19%
P/S	75	74%
P/U	18	18%
D/S	34	33%
D/U	28	25%
FP/P/S	61	60%
FP/P/U	14	14%
FP/D/S	15	14%
FP/D/U	11	10%
CP/P/S	14	14%
CP/P/U	4	4%
CP/D/S	19	19%
CP/D/U	17	15%

FP Fixed price
 CP Cost plus
 P Production
 D Development
 S Stable baseline
 U Unstable baseline

Table 16

Relationship From the 50% Completion Point

Characteristics/ Number of Contracts		Number With Stable CPIs	Percentage
FP	101	99	98%
CP	54	54	100%
P	93	93	100%
D	62	60	97%
S	109	108	99%
U	46	45	98%
FP/P	75	75	100%
FP/D	26	24	92%
FP/S	76	75	99%
FP/U	25	24	96%
CP/P	18	18	100%
CP/D	36	36	100%
CP/S	33	33	100%
CP/U	21	21	100%
P/S	75	75	100%
P/U	18	18	100%
D/S	34	33	97%
D/U	28	27	96%
FP/P/S	61	61	100%
FP/P/U	14	14	100%
FP/D/S	15	14	93%
FP/D/U	11	10	91%
CP/P/S	14	14	100%
CP/P/U	4	4	100%
CP/D/S	19	19	100%
CP/D/U	17	17	100%

FP Fixed price
 CP Cost plus
 P Production
 D Development
 S Stable baseline
 U Unstable baseline

Table 17

Results of Cumulative CPI Stability
by Contract Characteristics

Characteristics/ Number of Contracts		Stabilization Point (Percent Complete)			
		Maximum	Minimum	Mean	Standard Deviation
FP	101	70	0	11	14
CP	54	50	0	12	14
P	93	50	0	9	11
D	62	70	0	15	16
S	109	70	0	10	12
U	46	60	0	16	16
FP/P	75	50	0	10	12
FP/D	26	70	0	14	17
FP/S	76	70	0	11	14
FP/U	25	60	0	12	14
CP/P	18	10	0	6	5
CP/D	36	50	0	15	16
CP/S	33	20	0	7	6
CP/U	21	50	0	20	18
P/S	75	50	0	9	12
P/U	18	30	0	9	8
D/S	34	70	0	11	12
D/U	28	60	0	20	19
FP/P/S	61	50	0	10	13
FP/P/U	14	30	0	10	9
FP/D/S	15	70	0	14	17
FP/D/U	11	60	0	15	19
CP/P/S	14	10	0	6	5
CP/P/U	4	10	0	8	5
CP/D/S	19	20	0	8	6
CP/D/U	17	50	0	23	19

FP Fixed price
CP Cost plus
P Production
D Development
S Stable baseline
U Unstable baseline

Method of Least Squares. The value of the slopes calculated once the cumulative CPIs stabilize are listed in Table 18. The first two columns identify the stabilization points observed and the frequency of their occurrence. The third and fourth columns list the number of times a positive and negative slope are observed at the given stabilization point. The next two columns report the maximum and minimum slopes observed, while the final column identifies the mean slope. For example, of the 18 contracts that stabilized at the 20% completion point, 2 have positive slopes and 16 have negative slopes. The maximum slope observed is 0.033 and the minimum slope observed is -0.368, while -0.194 is the mean of the slopes.

Table 18
Relationship Between the Cumulative
CPI Slope and the Stabilization Point

Stabilization Point/Frequency		Slope				
		Total (+)	Total (-)	Maximum	Minimum	Mean
70	1	0	1	-0.770	-0.770	-0.770
60	1	0	1	-0.701	-0.701	-0.701
50	3	0	3	-0.438	-0.564	-0.486
40	9	0	9	-0.209	-0.501	-0.384
30	7	1	6	0.367	-0.442	-0.187
20	18	2	16	0.033	-0.368	-0.194
10	57	13	44	0.149	-0.244	-0.059
0	59	13	46	0.132	-0.182	-0.059

Analysis of Results

Non-cumulative CPI Values. The range method results indicate that the non-cumulative CPI values do not stabilize from the 50 percent completion point. Only 6% of the contracts investigated show stability for three month CPIs after the 50 percent completion point, 32% for six month CPIs, and 19% for six month moving average CPI values. Taking contract characteristics into consideration, the most stable non-cumulative CPI results occurred for contracts that are fixed price, in a development phase, and have stable baselines. For this particular set of contracts, 20% of the three month CPIs stabilize after the 50 percent completion point, 47% of the six month, and 27% of the six month moving average. The least stable non-cumulative CPI results occurred for contracts that are fixed price, in a development phase, and have unstable baselines. For this set of contracts, none of the non-cumulative CPI values stabilize after the 50 percent completion point.

Cumulative CPI Values. The range method results show that the cumulative CPI values are stable from the 50 percent completion point. In fact, the results provide evidence that the cumulative CPI stabilizes much earlier. Of the 155 contracts analyzed, 99% have stable cumulative CPIs from the 50% completion point, 97% from the 40% completion point, 91% from the 30% completion point, and 86% from the 20% completion point. The percentage of contracts with stable cumulative CPIs drops significantly from there

however, to 76% from the 10% completion point and 54% from contract start.

The confidence interval for the mean of the range calculations provide additional evidence that the cumulative CPI is stable from the 50% completion point and, in fact, from points much earlier. Considering a 99% confidence interval for the mean of the ranges from the 50% completion point, the upper limit is .080 and the lower limit is .058. For the mean of the ranges from the 10% completion point, the upper limit is .167 and the lower limit is .123. Only the calculations from the contract starting point provide an interval that is clearly beyond the .200 range stability limit. For the mean of the ranges from the 0% completion point, the upper limit is .314 and the lower limit is .210.

The study of the relationship between the cumulative CPI stabilization points and the contract characteristics also illustrate that the cumulative CPI is stable from the 50% completion point and, once again, from points earlier in the contract. Considering single contract characteristics, fixed price contracts stabilize before cost plus contracts (11 versus 12 percent complete), production contracts stabilize before development contracts (9 versus 15 percent complete), and contracts with stable baselines stabilize before contracts with unstable baselines (10 versus 16 percent complete). Considering a set of three contract characteristics, the earliest mean stabilization point is 6 percent complete for cost plus contracts in a production

phase with stable baselines. The latest mean stabilization point is 23 percent complete for cost plus contracts in a development phase with unstable baselines.

The results of the least squares method provide an explanation of the relationship between the cumulative CPI stabilization points and the contract characteristics. The method of least squares results indicate that the cumulative CPI tends to decline as the contract proceeds. This means that the cumulative CPI will stabilize at a later percent completion point for contracts with unstable baselines (significant increases in the BAC) than for contracts with stable baselines. For instance, consider the example illustrated in Figure 4. If the baseline for a contract remains stable (BAC equal to 100) and the observed cumulative CPI trend is $-.250$, the stabilization point is 20 percent complete (following the definition of CPI stability used in this study, a maximum allowable CPI range of $.200$). On the other hand, if the baseline becomes unstable (the BAC is increased to 140) and the cumulative CPI trend continues at $-.250$, the new stabilization point is 43 percent complete (60 divided into 140). Given this, and that cost plus/development contracts are more likely to have unstable baselines than fixed price/production contracts (see Table 17), it is expected that the cumulative CPI for contracts possessing the latter characteristics will stabilize first.

EXAMPLE OF INCREASING BASELINE STABILIZATION POINT OCCURS LATER

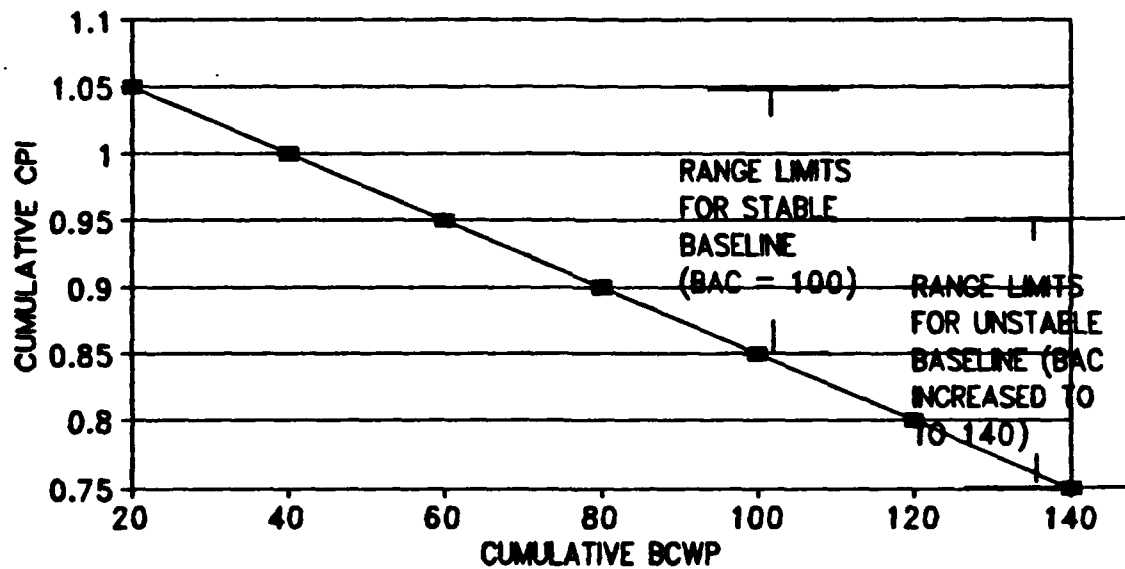


Figure 4. Impact of Increasing Baseline

This concludes the presentation of the calculations proposed by the methodology chapter. The next and final chapter draws a conclusion from these calculations, discusses the significance of the conclusion, and recommends ideas for further research.

V. Discussion

Review of the Hypotheses

For the three month, six month, six month moving average, and cumulative CPI, the hypothesis tested was that the CPI is stable when a contract is greater than 50 percent complete. The hypotheses were tested using a sample of 155 contracts from 44 different programs from the DAES database. The range method was the test used to determine CPI stability.

Conclusion

Only the cumulative CPI was stable after the 50 percent contract completion point. Further analyses, such as the sensitivity analysis, the confidence interval for the mean of the ranges, and the correlation of CPI stability with contract characteristics indicated the cumulative CPI is stable from the 20 percent contract completion point.

Discussion

The results show that the cumulative CPI is stable, and more stable than the other CPIs examined. Knowing that the cumulative CPI is stable (does not change by more than 10 percent) after a contract is 20 percent complete allows government personnel to determine the likelihood that a contractor can recover from a cost overrun and to project the final cost of the contract. For instance, consider a

contract that is 20 percent complete and has a current cumulative CPI less than 1.000 (indicating a cost overrun). If the TCPI (the level of cost performance the contractor must maintain for the remainder of the contract to complete the contract on budget) is calculated and found to be greater than 10 percent higher than the current cumulative CPI, the results of this study indicate that it is unlikely that the contractor can achieve the TCPI. Therefore, the contract will likely end with a cost overrun.

As a caveat, the results of the method of least squares indicate that the cumulative CPI does tend to decline within the allowable range limit (.200) as the contract proceeds. Therefore, even though the cumulative CPI is considered stable from the 20 percent completion point, the final cumulative CPI value can be expected to be lower. It is important to consider this when projecting the final cost of the contract. For example, consider a contract with a BAC of \$200 million. If the contract is currently 20 percent complete and it is assumed that the current cumulative CPI (.960) will equal the final CPI, the projected final cumulative ACWP is \$208.3 million (or a cost overrun of \$8.3 million).⁵ On the other hand, if a decline in the cumulative CPI is accounted for (the most likely outcome as shown by the method of least squares), from .960 to .900, the projected cost overrun is \$222.2 million (using the same

⁵ Reference formula (2) on page 11.

formula). This results in a negative cost overrun difference of approximately \$14 million. Therefore, a decline in the cumulative CPI should be accounted for when making early final cost projections because it provides a more likely estimate of the final cost of the contract. Furthermore, as the contract progresses, a method should be used (such as the method of least squares) to monitor the magnitude and direction of the cumulative CPI trend to further improve the accuracy of final cost projections.

Recommendations for Further Research

This study found that cumulative CPI values are more stable than non-cumulative CPI values. The cumulative CPI stabilized even though large variances among non-cumulative CPI values occurred after the 50% completion point. This suggests that cumulative CPI stability is not a result of things such as good managerial performance, but that the cumulative CPI stabilizes because it is a cumulative index.⁶ However, it is recommended that further causes for the disconnect between cumulative and non-cumulative cost performance stability be investigated. For instance, a study of the sensitivity of non-cumulative CPI values to the size of the BCWP is recommended. It was observed that the size of the three month and six month non-cumulative BCWP values diminished as the contract neared completion.

⁶ Refer to page 14.

Other recommendations to extend this study are to examine other contract characteristics (such as the dollar value of the contract), examine CPI stability at 5 percent (or less) rather than 10 percent completion intervals, and conduct a sensitivity analysis on the size of the range used to determine CPI stability.

Appendix A: Contracts Included in Study

Table 19

Contracts Listed by Name, Phase, Type, and
Stability of the Baseline (SB, Unstable or Stable)

Program/Contract	Phase	Type	SB
AH-64, Apache Helicopter (Army)			
Avionics, Lot III	FRP	FPIF	S
Airframe, Lot II	FRP	FPIF	S
Support Equipment, Lot II	FRP	FPIF	S
Avionics, Lot II	FRP	FPIF	S
Support Equipment, Lot I	FRP	FPIF	S
Avionics	FSD	CP	U
Avionics	FSD	CP	U
Engine	FSD	CP	U
Airframe	FSD	CP	U
AMRAAM Missile (Air Force)			
Missile (Leader)	FSD	FPIF	S
Missile (Follower)	FSD	FPIF	U
AN/BSY-1, Combat Data System (Navy)			
Submarine Electronics	FSD	CPIF	U
Submarine Electronics	FSD	CPAF	U
AN/SQQ-89, Anti-Submarine Warfare Combat System (Navy)			
Submarine Electronics	FSD	CP	S
Submarine Electronics	FSD	CP	S
Airborne Self Protection Jammer (Navy)			
Avionics	FSD	CPAF	S
Army Tactical Missile System (Army)			
Missile	FSD	FPIF	S
Ground Electronics	FSD	FPIF	S
B-1B, Strategic Bomber (Air Force)			
Airframe	FRP	FPIF	U
Offensive Avionics, Lot II	FRP	FPIF	U
Offensive Avionics, Lot V	FRP	FPIF	S
Defensive Avionics, Lot V	FRP	FPIF	S
Offensive Avionics	FRP	FPIF	U
Defensive Avionics, Lot II	FRP	FPIF	S
Engine, Lot I	FRP	FPIF	S

Defensive Avionics, Lot I	FRP	FPIF	U
Offensive Avionics, Lot I	FRP	FPIF	S
Bradley Fighting Vehicle (Army)			
Ammunition	FRP	FPIF	S
Vehicle	FRP	FPIF	S
Vehicle	FSD	CP	U
C/MH-53E, Stallion Helicopter (Navy)			
Aircraft Buy, FY79	FRP	FPIF	S
Aircraft Buy, FY78	FRP	FPIF	S
CG-47, AEGIS Cruiser (Navy)			
Cruiser 62-65	Const	FPIF	S
Cruiser 48, Yorktown	Const	CP	S
Cruiser 47, Ticonderoga	Const	CP	U
CH-47D, Chinook Helicopter (Army)			
Aircraft Buy, FY82	FRP	CP	S
Aircraft Buy, FY81	FRP	FPIF	S
DDG-51, Destroyer (Navy)			
Electronics	FSD	CPAF	S
Destroyer 51	Const	FPIF	U
Electronics	FRP	FPIF	S
Defense Satellite Communications System (Air Force)			
Booster	FSD	FPIF	S
Spacecraft	FSD	FPIF	U
F-15, Eagle Fighter Aircraft (Air Force)			
Avionics, Lot II	FRP	FPIF	U
Aircraft	FRP	FPIF	U
Avionics, Lot III	FRP	FPIF	S
Aircraft Buy, FY78	FRP	FPIF	S
Airframe	FSD	CP	U
Aircraft Buy, FY77	FRP	FPIF	S
F-16, Falcon Fighter Aircraft (Air Force)			
Aircraft Buy, FY79	FRP	FPIF	U
Airframe	FSD	FPIF	U
F/A-18, Hornet Fighter Aircraft (Navy)			
Engine	FSD	CP	S
Airframe	FSD	CP	U

HARPOON Missile (Navy) Missile	FRP	FPIF	S
HELLFIRE Missile (Army) Electronics, FY83	FRP	FPIF	S
Missile, FY83	FRP	FPIF	S
Missile, FY82	FRP	FPIF	S
Electronics, FY82	FRP	FPIF	S
Missile	FSD	CP	U
JSTARS (Air Force) Avionics	FSD	FPIF	S
JTIDS (Air Force) Avionics	FSD	FPIF	S
Landing Craft Air Cushion (Navy) Craft 13 and 14	Const	FPIF	S
Craft 24-33	Const	FPIF	S
Craft 15-23	Const	FPIF	S
M1A1 Abrams Tank (Army) Tank	FSD	CP	S
MAVERICK Missile (Air Force) Missile	FRP	FPIF	S
Missile	FSD	FPIF	U
MK 48, Advanced Capability Torpedo (Navy) Test Equipment	FRP	FPIF	U
MK 50, Torpedo (Navy) Torpedo	FSD	CPIF	U
MK-15, Phalanx Close In Weapon System (Navy) Gun/Electronics, FY86	FRP	FPIF	S
Gun/Electronics, FY87	FRP	FPIF	S
Multiple Launch Rocket System (Army) Launch Vehicle	FOD	CP	S
System	FOD	CP	S
NAVSTAR Global Positioning System (Air Force) Test Equipment	FSD	FPIF	U
Satellites	FRP	FPIF	U
Ground Electronics	FRP	FPIF	S
Avionics	FRP	FPIF	S
Software	FSD	CP	U
Spacecraft	FSD	FPIF	U

OH-58D, Army Helicopter Improvement Program (Army) Aircraft	FSD	FPIF	S
Over the Horizon Backscatter Radar (Air Force)			
Section 4	FRP	FPIF	S
Section 5	FRP	FPIF	S
PATRIOT Missile System (Army)			
Missile, FY85	FRP	FPIF	S
Production Facilities	FRP	CPIF	S
Missile, FY86	FRP	FPIF	S
Missile, FY84	FRP	FPIF	S
Missile, FY83	FRP	FPIF	S
Ground Electronics	FRP	CP	S
Missile, FY81	FRP	CP	S
Missile, FY80	FRP	CP	U
Missile	FSD	CP	U
PEACEKEEPER ICBM (Air Force)			
Canister	FRP	FPIF	U
Support Equipment	FRP	CPFF	U
Assembly and Checkout	FRP	FPIF	S
Electronics, FY84	FRP	FPIF	S
Electronics, FY86	FRP	CPFF	S
Stage III, FY86	FRP	FPIF	S
Electronics, FY84	FRP	FPIF	S
Support Equipment	FRP	CPIF	S
Stage IV, FY84	FRP	FPIF	S
Stage III, FY84	FRP	FPIF	S
Stage II, FY84	FRP	FPIF	S
Stage I, FY84	FRP	FPIF	S
Re-entry System	FOD	FPIF	S
Stage II	FOD	FPIF	S
Stage IV	FOD	FPIF	S
Stage III	FOD	FPIF	S
Stage I	FOD	FPIF	S
Electronics	FOD	CPIF	S
Re-entry Vehicle	FSD	FPIF	S
Electronics	FOD	FPIF	U
Electronics	FOD	FPIF	S
Electronics	FSD	CP	S
Re-entry System	FSD	CP	S
PHOENIX Missile (Navy)			
Electronics	FRP	FPIF	S
Sea Lance Anti-Submarine Stand-Off Weapon (Navy) System	DEM/VAL	CPAF	U

SH-60B, Seahawk Helicopter Light Airborne Multi-Purpose System (Navy)			
Engine	FSD	CP	S
Airframe	FSD	CP	S
Software	FSD	CP	S
SMALL ICBM (Air Force)			
Stage II	FSD	FPIF	U
Stage III	FSD	FPIF	U
Hard Mobile Basing	FSD	FPIF	U
Firing System	FSD	FPIF	U
SSN 688 Attack Submarine (Navy) SSN 700-710			
	Const	FPIF	S
Standard Missile 2, Block II (Navy)			
Electronics	FRP	FPIF	S
STINGER Missile (Army)			
Missile, FY85	FRP	FPIF	S
Missile, FY86	FRP	FPIF	S
Missile	FOD	FPIF	S
Electronics	LRIP	FPIF	U
Missile, FY82	FRP	FPIF	S
Missile, FY79-81	FRP	FPIF	U
Missile, FY78	FRP	FPIF	S
Electronics	FSD	CP	U
Missile	FSD	CP	U
TOMOHAWK Missile (Navy)			
Electronics, FY81	FRP	CP	S
Electronics	FSD	CP	S
TRIDENT II D5 Missile (Navy)			
Electronics	FRP	CPIF	S
Electronics	FRP	CPFF	S
Electronics	FRP	CPIF	S
Electronics	FRP	CPIF	S
Electronics	FRP	CPIF	S
Electronics	FRP	CPIF	S
Electronics	FRP	CPIF	U
TRIDENT II Submarine (Navy)			
Submarine Group IV	Const	FPIF	U
Submarine Group V	Const	FPIF	S
UH-60A, Blackhawk Helicopter (Army)			
Airframe, Lot IV	FRP	FPIF	S
Airframe, Lot III	FRP	FPIF	S

Airframe, Lot II	FRP	FPIF	S
Electronics	FSD	CP	S
Electronics	FOD	CP	S
Engine, Lot II	FRP	FPIF	S
Engine, Lot I	FRP	FPIF	S
Airframe, Lot I	FRP	FPIF	S
Engine	FSD	CP	S
Airframe	FSD	CP	S
V-22A Osprey Aircraft (Navy)			
Aircraft	DEM/VAL	CP	U

Appendix B: Results for Non-cumulative Values

Table 20

**Range From 50% Completion Point for Quarterly (Q),
Six Month (SM), and Six Month Moving Average (SMMA) Values**

Program/Contract	Q	SM	SMMA
AH-64, Apache Helicopter (Army)			
Avionics, Lot III	0.617	0.212	0.461
Airframe, Lot II	0.519	0.269	0.301
Support Equipment, Lot II	2.990	0.256	0.278
Avionics, Lot II	0.376	0.379	0.379
Support Equipment, Lot I	0.170	0.001	0.063
Avionics	0.399	0.149	0.296
Avionics	0.377	0.182	0.266
Engine	0.476	0.272	0.293
Airframe	0.699	0.356	0.524
AMRAAM Missile (Air Force)			
Missile (Leader)	1.490	0.445	0.642
Missile (Follower)	1.126	0.823	0.878
AN/BSY-1, Combat Data System (Navy)			
Submarine Electronics	0.611	0.884	0.917
Submarine Electronics	2.894	1.702	1.966
AN/SQQ-89, Anti-Submarine Warfare Combat System (Navy)			
Submarine Electronics	0.897	0.398	0.605
Submarine Electronics	0.321	0.249	0.249
Airborne Self Protection Jammer (Navy)			
Avionics	1.986	0.236	1.201
Army Tactical Missile System (Army)			
Missile	1.980	0.340	0.343
Ground Electronics	0.333	0.199	0.233
B-1B, Strategic Bomber (Air Force)			
Airframe	0.825	0.381	0.381
Offensive Avionics, Lot II	0.479	0.405	0.405
Offensive Avionics, Lot V	0.356	0.220	0.222
Defensive Avionics, Lot V	0.444	0.086	0.301
Offensive Avionics	0.270	0.103	0.140
Defensive Avionics, Lot II	7.412	0.080	1.595
Engine, Lot I	2.042	0.260	0.339

Defensive Avionics, Lot I	1.132	0.654	0.654
Offensive Avionics, Lot I	0.430	0.285	0.285
Bradley Fighting Vehicle (Army)			
Ammunition	0.607	0.119	0.155
Vehicle	0.100	0.031	0.124
Vehicle	2.119	0.893	0.893
C/MH-53E, Stallion Helicopter (Navy)			
Aircraft Buy, FY79	0.886	0.669	0.669
Aircraft Buy, FY78	2.123	0.416	1.070
CG-47, AEGIS Cruiser (Navy)			
Cruiser 62-65	0.718	0.310	0.407
Cruiser 48, Yorktown	0.413	0.010	0.357
Cruiser 47, Ticonderoga	1.886	0.895	1.242
CH-47D, Chinook Helicopter (Army)			
Aircraft Buy, FY82	0.411	0.013	0.036
Aircraft Buy, FY81	0.224	0.195	0.195
DDG-51, Destroyer (Navy)			
Electronics	1.005	0.825	0.825
Destroyer 51	0.543	0.254	0.329
Electronics	0.404	0.140	0.142
Defense Satellite Communications System (Air Force)			
Booster	0.396	0.276	0.276
Spacecraft	1.155	0.699	0.914
F-15, Eagle Fighter Aircraft (Air Force)			
Avionics, Lot II	1.035	0.463	0.804
Aircraft	0.673	0.367	0.367
Avionics, Lot III	0.221	0.019	0.118
Aircraft Buy, FY78	0.244	0.069	0.104
Airframe	7.639	4.615	4.651
Aircraft Buy, FY77	0.737	0.030	0.285
F-16, Falcon Fighter Aircraft (Air Force)			
Aircraft Buy, FY79	0.997	0.487	0.487
Airframe	0.792	0.233	0.352
F/A-18, Hornet Fighter Aircraft (Navy)			
Engine	1.154	0.748	0.869
Airframe	0.843	0.525	0.525
HARPOON Missile (Navy)			
Missile	0.454	0.282	0.282

HELLFIRE Missile (Army)			
Electronics, FY83	0.418	0.169	0.517
Missile, FY83	1.652	0.130	0.499
Missile, FY82	1.155	0.912	0.912
Electronics, FY82	2.000	0.501	0.582
Missile	1.134	0.364	0.710
JSTARS (Air Force)			
Avionics	1.275	0.578	0.667
JTIDS (Air Force)			
Avionics	0.639	0.375	0.375
Landing Craft Air Cushion (Navy)			
Craft 13 and 14	3.159	2.163	2.163
Craft 24-33	0.317	0.211	0.211
Craft 15-23	1.079	0.204	0.418
M1A1 Abrams Tank (Army)			
Tank	0.222	0.184	0.184
MAVERICK Missile (Air Force)			
Missile	0.326	0.109	0.238
Missile	0.358	0.360	0.360
MK 48, Advanced Capability			
Torpedo (Navy)			
Test Equipment	0.337	0.278	0.310
MK 50, Torpedo (Navy)			
Torpedo	1.675	1.085	1.094
MK-15, Phalanx Close In Weapon			
System (Navy)			
Gun/Electronics, FY86	0.379	0.320	0.320
Gun/Electronics, FY87	0.564	0.506	0.506
Multiple Launch Rocket System			
(Army)			
Launch Vehicle	3.868	0.564	0.681
System	0.452	0.091	0.180
NAVSTAR Global Positioning System			
(Air Force)			
Test Equipment	0.924	0.343	0.484
Satellites	0.490	0.345	0.345
Ground Electronics	0.688	0.324	0.451
Avionics	0.406	0.271	0.314
Software	1.379	0.641	0.689
Spacecraft	0.362	0.257	0.267

OH-58D, Army Helicopter Improvement Program (Army) Aircraft	1.271	0.453	0.498
Over the Horizon Backscatter Radar (Air Force)			
Section 4	0.831	0.234	0.433
Section 5	2.000	0.410	0.410
PATRIOT Missile System (Army)			
Missile, FY85	1.170	0.685	0.738
Production Facilities	1.288	0.850	0.929
Missile, FY86	0.571	0.260	0.397
Missile, FY84	0.737	0.394	0.394
Missile, FY83	4.536	2.887	2.887
Ground Electronics	0.520	0.202	0.442
Missile, FY81	0.992	0.797	0.937
Missile, FY80	0.802	0.623	0.623
Missile	1.017	0.429	0.429
PEACEKEEPER ICBM (Air Force)			
Canister	0.299	0.138	0.177
Support Equipment	0.307	0.184	0.217
Assembly and Checkout	0.226	0.200	0.200
Electronics, FY84	0.526	0.393	0.421
Electronics, FY86	0.373	0.135	0.234
Stage III, FY86	0.900	0.283	0.818
Electronics, FY84	0.172	0.128	0.128
Support Equipment	0.206	0.109	0.110
Stage IV, FY84	0.073	0.023	0.036
Stage III, FY84	0.143	0.150	0.150
Stage II, FY84	0.291	0.237	0.244
Stage I, FY84	0.238	0.173	0.173
Re-entry System	0.161	0.009	0.054
Stage II	0.221	0.077	0.115
Stage IV	0.131	0.091	0.091
Stage III	0.177	0.175	0.175
Stage I	0.273	0.199	0.203
Electronics	0.162	0.004	0.101
Re-entry Vehicle	0.594	0.256	0.406
Electronics	0.487	0.282	0.327
Electronics	0.318	0.120	0.256
Electronics	0.694	0.358	0.358
Re-entry System	0.270	0.173	0.230
PHOENIX Missile (Navy)			
Electronics	0.208	0.137	0.174
Sea Lance Anti-Submarine Stand-Off Weapon (Navy) System	0.152	0.021	0.052

SH-60B, Seahawk Helicopter Light			
Airborne Multi-Purpose System			
(Navy)			
Engine	1.178	0.975	0.975
Airframe	0.842	0.414	0.414
Software	0.578	0.239	0.357
SMALL ICBM (Air Force)			
Stage II	1.170	0.604	0.604
Stage III	3.952	1.758	1.886
Hard Mobile Basing	1.308	0.552	0.887
Firing System	4.123	1.684	1.998
SSN 688 Attack Submarine (Navy)			
SSN 700-710	0.468	0.203	0.291
Standard Missile 2, Block II			
(Navy)			
Electronics	0.716	0.386	0.426
STINGER Missile (Army)			
Missile, FY85	0.979	0.111	0.246
Missile, FY86	0.892	0.454	0.509
Missile	0.581	0.510	0.510
Electronics	0.442	0.337	0.337
Missile, FY82	0.246	0.036	0.124
Missile, FY79-81	0.368	0.081	0.246
Missile, FY78	0.788	0.489	0.595
Electronics	0.479	0.310	0.310
Missile	0.946	0.626	0.626
TOMOHAWK Missile (Navy)			
Electronics, FY81	1.512	0.034	0.496
Electronics	0.608	0.344	0.344
TRIDENT II D5 Missile (Navy)			
Electronics	0.717	0.442	0.442
Electronics	0.633	0.421	0.421
Electronics	1.685	0.817	0.817
Electronics	0.424	0.149	0.366
Electronics	17.738	1.031	1.062
Electronics	1.032	0.635	0.635
Electronics	0.789	0.311	0.337
TRIDENT II Submarine (Navy)			
Submarine Group IV	2.833	0.478	1.075
Submarine Group V	0.376	0.128	0.292
UH-60A, Blackhawk Helicopter			
(Army)			
Airframe, Lot IV	0.546	0.101	0.201
Airframe, Lot III	0.914	0.143	0.153

Airframe, Lot II	1.120	0.350	0.995
Electronics	2.000	0.354	1.521
Electronics	0.709	0.392	0.449
Engine, Lot II	0.239	0.143	0.087
Engine, Lot I	1.803	0.230	0.628
Airframe, Lot I	0.254	0.106	0.117
Engine	1.181	0.787	0.907
Airframe	0.446	0.366	0.366
V-22A Osprey Aircraft (Navy)			
Aircraft	0.526	0.434	0.434

Appendix C: Results of Range Method for Cumulative Values

Table 21

Range From Given Percent
Completion Point To Final CPR Entry

Program/Contract	0%	10%	Percent Complete			50%
			20%	30%	40%	
AH-64, Apache						
Helicopter (Army)						
Avionics, Lot III	0.249	0.249	0.228	0.178	0.178	0.178
Airframe, Lot II	0.183	0.111	0.055	0.055	0.055	0.055
Support Equipment	0.277	0.277	0.277	0.179	0.076	0.076
Avionics, Lot II		0.264	0.264	0.264	0.141	0.111
Support Equipment	0.764	0.189	0.081	0.037	0.037	0.027
Avionics	0.312	0.303	0.303	0.276	0.234	0.158
Avionics		0.317	0.290	0.226	0.226	0.161
Engine	0.128	0.088	0.088	0.035	0.035	0.035
Airframe	0.221	0.221	0.221	0.215	0.200	0.178
AMRAAM Missile						
(Air Force)						
Missile	0.508	0.500	0.419	0.359	0.312	0.299
Missile		0.123	0.123	0.123	0.123	0.123
AN/BSY-1, Combat						
Data System (Navy)						
Electronics		0.148	0.148	0.148	0.148	0.050
Electronics			0.138	0.138	0.138	0.138
AN/SQQ-89, Anti-						
Submarine						
Warfare Combat						
System (Navy)						
Electronics		0.147	0.115	0.115	0.077	0.069
Electronics		0.085	0.085	0.051	0.036	0.036
Airborne Self						
Protection						
Jammer (Navy)						
Avionics	0.653	0.420	0.194	0.069	0.069	0.069
Army Tactical						
Missile						
System (Army)						
Missile		0.122	0.122	0.096	0.093	0.069
Ground Electronics	0.368	0.284	0.207	0.168	0.168	0.127

**B-1B, Strategic
Bomber (Air Force)**

Airframe		0.111	0.063	0.063	0.063	0.063
Avionics, Lot II	0.169	0.114	0.101	0.066	0.066	0.066
Avionics, Lot V	0.074	0.017	0.017	0.007	0.007	0.007
Avionics, Lot V		0.069	0.069	0.069	0.069	0.057
Avionics		0.018	0.017	0.017	0.017	0.017
Avionics, Lot II	0.142	0.098	0.098	0.098	0.098	0.046
Engine, Lot I		0.067	0.038	0.038	0.025	0.025
Avionics, Lot I	0.092	0.070	0.032	0.024	0.024	0.024
Avionics, Lot I	0.017	0.017	0.017	0.009	0.005	0.005

**Bradley Fighting
Vehicle (Army)**

Ammunition	0.167	0.149	0.047	0.024	0.022	0.022
Vehicle	0.213	0.213	0.132	0.132	0.132	0.082
Vehicle	0.363	0.318	0.210	0.210	0.177	0.155

**C/MH-53E, Stallion
Helicopter (Navy)**

Aircraft Buy, FY79	0.411	0.108	0.075	0.075	0.075	0.075
Aircraft Buy, FY78	0.433	0.135	0.135	0.135	0.121	0.121

**CG-47, AEGIS Cruiser
(Navy)**

Cruiser 62-65		0.066	0.046	0.039	0.039	0.039
Cruiser 48		0.053	0.042	0.032	0.032	0.032
Cruiser 47	0.532	0.144	0.144	0.115	0.115	0.115

CH-47D, Chinook

Helicopter (Army)						
Aircraft Buy, FY82	0.156	0.095	0.043	0.012	0.003	0.003
Aircraft Buy, FY81	0.104	0.104	0.070	0.040	0.040	0.040

**DDG-51, Destroyer
(Navy)**

Electronics	0.205	0.173	0.107	0.107	0.107	0.053
Destroyer 51	0.368	0.282	0.173	0.072	0.072	0.072
Electronics		0.052	0.031	0.031	0.020	0.020

**Defense Satellite
Communications
System (Air Force)**

Booster	0.201	0.201	0.153	0.153	0.128	0.084
Spacecraft		0.259	0.259	0.259	0.259	0.243

F-15, Eagle

Fighter Aircraft (Air Force)						
Avionics, Lot II			0.165	0.145	0.145	0.145
Aircraft		0.071	0.071	0.071	0.046	0.046
Avionics, Lot III	0.230	0.204	0.179	0.163	0.103	0.042

Aircraft Buy, FY78	0.065	0.065	0.065	0.065	0.020	0.009
Airframe	0.083	0.062	0.043	0.028	0.028	0.028
Aircraft Buy, FY77	0.108	0.108	0.054	0.053	0.026	0.021
F-16, Falcon						
Fighter Aircraft						
(Air Force)						
Aircraft Buy, FY79		0.071	0.071	0.071	0.071	0.071
Airframe	0.188	0.048	0.032	0.030	0.022	0.022
F/A-18, Hornet						
Fighter Aircraft						
(Navy)						
Engine	0.082	0.062	0.062	0.062	0.062	0.062
Airframe	0.361	0.213	0.206	0.199	0.164	0.164
HARPOON Missile						
(Navy)						
Missile	0.185	0.112	0.056	0.056	0.056	0.056
HELLFIRE Missile						
(Army)						
Electronics, FY83	1.182	0.307	0.250	0.212	0.212	0.161
Missile, FY83	1.243	0.408	0.272	0.198	0.102	0.102
Missile, FY82	0.625	0.208	0.208	0.208	0.195	0.195
Electronics, FY82	0.288	0.288	0.093	0.093	0.093	0.093
Missile	0.178	0.178	0.178	0.178	0.106	0.090
JSTARS (Air Force)						
Avionics		0.113	0.107	0.107	0.107	0.104
JTIDS (Air Force)						
Avionics		0.193	0.157	0.157	0.111	0.088
Landing Craft Air						
Cushion (Navy)						
Craft 13 and 14	0.091	0.091	0.091	0.091	0.091	0.091
Craft 24-33	0.071	0.039	0.039	0.039	0.039	0.039
Craft 15-23	0.169	0.089	0.071	0.071	0.069	0.069
M1A1 Abrams Tank						
(Army)						
Tank	0.113	0.113	0.104	0.104	0.104	0.077
MAVERICK Missile						
(Air Force)						
Missile	0.156	0.138	0.138	0.081	0.067	0.037
Missile	0.615	0.213	0.196	0.195	0.157	0.144
MK 48, Advanced						
Capability						
Torpedo (Navy)						
Test Equipment	0.145	0.126	0.074	0.074	0.042	0.040

MK 50, Torpedo (Navy) Torpedo	0.141	0.127	0.127	0.127	0.127	0.127
MK-15, Phalanx Close In Weapon System (Navy) Gun, FY86	0.117	0.049	0.049	0.049	0.030	0.030
Gun, FY87	0.207	0.108	0.108	0.108	0.105	0.101
Multiple Launch Rocket System (Army) Launch Vehicle System	0.336	0.146 0.135	0.146 0.135	0.146 0.090	0.146 0.042	0.146 0.030
NAVSTAR Global Positioning System (Air Force) Test Equipment	0.246	0.214	0.197	0.142	0.107	0.097
Satellites	0.217	0.217	0.217	0.039	0.039	0.039
Ground Electronics	0.477	0.341	0.162	0.112	0.082	0.059
Avionics	0.266	0.172	0.051	0.029	0.025	0.025
Software	0.476	0.428	0.368	0.236	0.186	0.137
Spacecraft	0.349	0.228	0.228	0.179	0.109	0.049
OH-58D, Army Heli- copter Improvement Program (Army) Aircraft	0.132	0.096	0.096	0.096	0.096	0.096
Over the Horizon Backscatter Radar (Air Force) Section 4	0.099	0.074	0.041	0.041	0.041	0.041
Section 5	0.155	0.063	0.063	0.058	0.021	0.021
PATRIOT Missile System (Army) Missile, FY85	0.273	0.102	0.102	0.061	0.053	0.041
Facilities	0.444	0.080	0.065	0.058	0.058	0.052
Missile, FY86	0.100	0.100	0.100	0.068	0.054	0.046
Missile, FY84		0.088	0.028	0.024	0.024	0.024
Missile, FY83	0.096	0.096	0.080	0.073	0.048	0.048
Ground Electronics	0.096	0.096	0.096	0.096	0.096	0.096
Missile, FY81	0.368	0.142	0.142	0.142	0.142	0.140
Missile, FY80	0.675	0.124	0.124	0.124	0.124	0.086
Missile		0.083	0.051	0.051	0.046	0.046
PEACEKEEPER ICBM (Air Force) Canister		0.067	0.039	0.039	0.039	0.039
Support Equipment		0.082	0.077	0.077	0.077	0.077

Assembly	0.154	0.080	0.062	0.062	0.062	0.062
Electronics, FY84	0.228	0.228	0.186	0.148	0.116	0.112
Electronics, FY86		0.050	0.050	0.050	0.050	0.041
Stage III, FY86		0.131	0.111	0.111	0.111	0.079
Electronics, FY84	0.088	0.049	0.049	0.043	0.043	0.036
Support Equipment		0.051	0.045	0.035	0.015	0.015
Stage IV, FY84	0.501	0.152	0.152	0.082	0.015	0.015
Stage III, FY84	0.177	0.046	0.046	0.046	0.046	0.046
Stage II, FY84	0.215	0.215	0.158	0.158	0.127	0.072
Stage I, FY84	0.198	0.175	0.144	0.124	0.042	0.042
Re-entry System	0.074	0.040	0.028	0.028	0.026	0.024
Stage II		0.106	0.036	0.035	0.028	0.019
Stage IV		0.066	0.059	0.028	0.024	0.019
Stage III		0.187	0.187	0.100	0.076	0.058
Stage I		0.068	0.068	0.040	0.040	0.028
Electronics	0.018	0.018	0.018	0.018	0.016	0.014
Re-entry Vehicle		0.084	0.084	0.059	0.059	0.043
Electronics	0.704	0.338	0.145	0.098	0.053	0.053
Electronics	0.092	0.029	0.029	0.029	0.029	0.029
Electronics		0.127	0.127	0.127	0.081	0.005
Re-entry System		0.145	0.102	0.098	0.085	0.081
PHOENIX Missile						
(Navy)						
Electronics	0.194	0.091	0.091	0.057	0.057	0.037
Sea Lance Anti-						
Submarine Stand-Off						
Weapon (Navy)						
System			0.026	0.017	0.014	0.014
SH-60B, Seahawk						
Helicopter LAMP						
System (Navy)						
Engine	0.280	0.241	0.151	0.139	0.117	0.113
Airframe	0.215	0.146	0.095	0.035	0.030	0.030
Software		0.174	0.101	0.066	0.054	0.054
SMALL ICBM						
(Air Force)						
Stage II	0.122	0.047	0.047	0.047	0.047	0.047
Stage III	0.120	0.120	0.120	0.120	0.092	0.092
Mobile Basing	0.166	0.041	0.041	0.041	0.041	0.041
Firing System	0.159	0.130	0.130	0.130	0.130	0.130
SSN 688 Attack						
Submarine (Navy)						
SSN 700-710	0.644	0.644	0.077	0.077	0.077	0.038
Standard Missile 2,						
Block II (Navy)						
Electronics		0.304	0.227	0.227	0.199	0.199

STINGER Missile**(Army)**

Missile, FY85	0.184	0.116	0.116	0.072	0.072	0.035
Missile, FY86	0.190	0.085	0.085	0.073	0.073	0.073
Missile	0.368	0.164	0.103	0.103	0.103	0.103
Electronics	0.325	0.164	0.126	0.098	0.096	0.096
Missile, FY82	0.077	0.048	0.048	0.048	0.047	0.022
Missile, FY79-81	0.319	0.174	0.151	0.097	0.071	0.026
Missile, FY78	0.535	0.257	0.257	0.257	0.178	0.178
Electronics	0.581	0.470	0.434	0.364	0.178	0.151
Missile	0.268	0.268	0.268	0.216	0.194	0.183

TOMOHAWK Missile**(Navy)**

Electronics, FY81		0.128	0.128	0.128	0.128	0.058
Electronics		0.114	0.114	0.053	0.041	0.040

TRIDENT II D5**Missile (Navy)**

Electronics		0.095	0.095	0.043	0.043	0.039
Electronics	0.159	0.046	0.046	0.030	0.030	0.028
Electronics	0.143	0.143	0.143	0.137	0.132	0.106
Electronics	0.098	0.071	0.070	0.047	0.033	0.024
Electronics		0.070	0.069	0.036	0.036	0.036
Electronics	0.140	0.089	0.089	0.044	0.044	0.044
Electronics	0.118	0.055	0.055	0.042	0.039	0.039

TRIDENT II**Submarine (Navy)**

Group IV	0.142	0.115	0.088	0.067	0.067	0.059
Group V		0.081	0.081	0.050	0.050	0.033

UH-60A, Blackhawk**Helicopter (Army)**

Airframe, Lot IV	0.113	0.088	0.088	0.088	0.052	0.052
Airframe, Lot III	0.172	0.172	0.064	0.029	0.029	0.027
Airframe, Lot II	0.319	0.056	0.056	0.056	0.052	0.045
Electronics		0.068	0.055	0.055	0.043	0.043
Electronics	0.217	0.114	0.114	0.114	0.114	0.082
Engine, Lot II	0.139	0.068	0.068	0.045	0.045	0.013
Engine, Lot I	0.074	0.061	0.061	0.061	0.058	0.058
Airframe, Lot I	0.599	0.232	0.141	0.141	0.054	0.052
Engine	0.094	0.030	0.030	0.030	0.030	0.030
Airframe	0.173	0.173	0.100	0.100	0.100	0.100

V-22A Osprey**Aircraft (Navy)**

Aircraft	0.183	0.183	0.148	0.092	0.092	0.088
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Appendix D: Slope Calculations for Cumulative Values

Table 22

**Percent Completion Point Data Starts (DS),
CPI Stabilization Point (SP), Range, and CPI Slope**

Program/Contract	DS	SP	Range	Slope
AH-64, Apache Helicopter (Army)				
Avionics, Lot III	0	30	0.178	-0.442
Airframe, Lot II	0	0	0.183	-0.083
Support Equipment, Lot II	0	30	0.179	0.367
Avionics, Lot II	10	40	0.141	-0.396
Support Equipment, Lot I	0	10	0.189	0.004
Avionics	0	50	0.158	-0.457
Avionics	10	50	0.161	-0.438
Engine	0	0	0.128	-0.080
Airframe	0	40	0.200	-0.440
AMRAAM Missile (Air Force)				
Missile (Leader)	0	70	0.186	-0.770
Missile (Follower)	10	10	0.123	-0.059
AN/BSY-1, Combat Data System (Navy)				
Submarine Electronics	10	10	0.148	0.032
Submarine Electronics	20	20	0.138	0.033
AN/SQQ-89, Anti-Submarine Warfare Combat System (Navy)				
Submarine Electronics	10	10	0.147	-0.063
Submarine Electronics	10	10	0.085	-0.030
Airborne Self Protection Jammer (Navy)				
Avionics	0	20	0.194	-0.231
Army Tactical Missile System (Army)				
Missile	10	10	0.122	-0.124
Ground Electronics	0	30	0.168	-0.368
B-1B, Strategic Bomber (Air Force)				
Airframe	10	10	0.111	-0.098
Offensive Avionics, Lot II	0	0	0.169	-0.140
Offensive Avionics, Lot V	0	0	0.074	-0.055
Defensive Avionics, Lot V	10	10	0.069	-0.025
Offensive Avionics	10	10	0.018	0.005
Defensive Avionics, Lot II	0	0	0.142	-0.153

Engine, Lot I	10	10	0.067	-0.045
Defensive Avionics, Lot I	0	0	0.092	-0.073
Offensive Avionics, Lot I	0	0	0.017	-0.013
Bradley Fighting Vehicle (Army)				
Ammunition	0	0	0.167	-0.114
Vehicle	0	20	0.132	-0.242
Vehicle	0	40	0.177	-0.501
C/MH-53E, Stallion				
Helicopter (Navy)				
Aircraft Buy, FY79	0	10	0.108	-0.021
Aircraft Buy, FY78	0	10	0.135	-0.152
CG-47, AEGIS Cruiser (Navy)				
Cruiser 62-65	10	10	0.066	0.041
Cruiser 48, Yorktown	10	10	0.053	-0.028
Cruiser 47, Ticonderoga	0	10	0.144	-0.070
CH-47D, Chinook Helicopter (Army)				
Aircraft Buy, FY82	0	0	0.156	-0.036
Aircraft Buy, FY81	0	0	0.104	-0.088
DDG-51, Destroyer (Navy)				
Electronics	0	10	0.173	-0.088
Destroyer 51	0	20	0.173	-0.196
Electronics	10	10	0.052	0.049
Defense Satellite Communications				
System (Air Force)				
Booster	0	20	0.153	-0.326
Spacecraft	10	60	0.198	-0.701
F-15, Eagle Fighter Aircraft				
(Air Force)				
Avionics, Lot II	20	20	0.165	-0.001
Aircraft	10	10	0.071	-0.060
Avionics, Lot III	0	20	0.179	-0.368
Aircraft Buy, FY78	0	0	0.065	-0.056
Airframe	0	0	0.083	0.015
Aircraft Buy, FY77	0	0	0.108	-0.082
F-16, Falcon Fighter Aircraft				
(Air Force)				
Aircraft Buy, FY79	10	10	0.071	-0.006
Airframe	0	0	0.188	-0.074
F/A-18, Hornet Fighter Aircraft				
(Navy)				
Engine	0	0	0.082	-0.034
Airframe	0	30	0.199	-0.361

HARPOON Missile (Navy)				
Missile	0	0	0.185	0.014
HELLFIRE Missile (Army)				
Electronics, FY83	0	50	0.161	-0.564
Missile, FY83	0	30	0.198	-0.228
Missile, FY82	0	40	0.195	-0.246
Electronics, FY82	0	20	0.093	-0.083
Missile	0	0	0.178	-0.159
JSTARS (Air Force)				
Avionics	10	10	0.113	0.035
JTIDS (Air Force)				
Avionics	10	10	0.193	-0.222
Landing Craft Air Cushion (Navy)				
Craft 13 and 14	0	0	0.091	-0.022
Craft 24-33	0	0	0.071	0.008
Craft 15-23	0	0	0.169	0.036
M1A1 Abrams Tank (Army)				
Tank	0	0	0.113	-0.117
MAVERICK Missile (Air Force)				
Missile	0	0	0.156	-0.173
Missile	0	20	0.196	-0.322
MK 48, Advanced Capability				
Torpedo (Navy)				
Test Equipment	0	0	0.145	0.036
MK 50, Torpedo (Navy)				
Torpedo	0	0	0.141	0.011
MK-15, Phalanx Close In Weapon				
System (Navy)				
Gun/Electronics, FY86	0	0	0.117	0.006
Gun/Electronics, FY87	0	10	0.108	-0.036
Multiple Launch Rocket System				
(Army)				
Launch Vehicle	10	10	0.146	-0.119
System	0	10	0.135	-0.151
NAVSTAR Global Positioning System				
(Air Force)				
Test Equipment	0	20	0.197	-0.290
Satellites	0	30	0.039	-0.062
Ground Electronics	0	20	0.162	-0.201
Avionics	0	10	0.172	-0.130
Software	0	40	0.186	-0.209
Spacecraft	0	30	0.179	-0.216

OH-58D, Army Helicopter Improvement Program (Army) Aircraft	0	0	0.132	-0.010
Over the Horizon Backscatter Radar (Air Force)				
Section 4	0	0	0.099	-0.082
Section 5	0	0	0.155	-0.155
PATRIOT Missile System (Army)				
Missile, FY85	0	10	0.102	0.101
Production Facilities	0	10	0.080	0.026
Missile, FY86	0	0	0.100	0.082
Missile, FY84	10	10	0.088	0.070
Missile, FY83	0	0	0.096	-0.025
Ground Electronics	0	0	0.096	-0.039
Missile, FY81	0	10	0.142	-0.112
Missile, FY80	0	10	0.124	-0.155
Missile	10	10	0.083	-0.067
PEACEKEEPER ICBM (Air Force)				
Canister	10	10	0.067	-0.072
Support Equipment	10	10	0.082	-0.112
Assembly and Checkout	0	0	0.154	-0.077
Electronics, FY84	0	20	0.186	-0.247
Electronics, FY86	10	10	0.050	-0.026
Stage III, FY86	10	10	0.131	0.149
Electronics, FY84	0	0	0.088	-0.058
Support Equipment	10	10	0.051	-0.022
Stage IV, FY84	0	10	0.152	-0.238
Stage III, FY84	0	0	0.177	-0.109
Stage II, FY84	0	20	0.158	-0.326
Stage I, FY84	0	0	0.198	-0.129
Re-entry System	0	0	0.074	-0.035
Stage II	10	10	0.106	-0.095
Stage IV	10	10	0.066	-0.074
Stage III	10	10	0.187	-0.244
Stage I	10	10	0.068	-0.056
Electronics	0	0	0.018	-0.015
Re-entry Vehicle	10	10	0.084	-0.084
Electronics	0	20	0.145	-0.217
Electronics	0	0	0.092	0.045
Electronics	10	10	0.127	0.132
Re-entry System	10	10	0.145	-0.182
PHOENIX Missile (Navy)				
Electronics	0	0	0.194	-0.182
Sea Lance Anti-Submarine Stand-Off Weapon (Navy) System	20	20	0.026	0.002

SH-60B, Seahawk Helicopter Light				
Airborne Multi-Purpose				
System (Navy)				
Engine	0	20	0.151	-0.124
Airframe	0	10	0.146	-0.102
Software	10	10	0.174	-0.147
SMALL ICBM (Air Force)				
Stage II	0	0	0.122	-0.078
Stage III	0	0	0.120	0.006
Hard Mobile Basing	0	0	0.166	0.087
Firing System	0	0	0.159	-0.091
SSN 688 Attack Submarine (Navy)				
SSN 700-710	0	20	0.077	-0.115
Standard Missile 2, Block II				
(Navy)				
Electronics	10	40	0.199	-0.490
STINGER Missile (Army)				
Missile, FY85	0	0	0.184	-0.174
Missile, FY86	0	0	0.190	-0.125
Missile	0	10	0.164	-0.145
Electronics	0	10	0.164	-0.099
Missile, FY82	0	0	0.077	-0.055
Missile, FY79-81	0	10	0.174	-0.181
Missile, FY78	0	40	0.178	-0.383
Electronics	0	40	0.178	-0.318
Missile	0	40	0.194	-0.476
TOMOHAWK Missile (Navy)				
Electronics, FY81	10	10	0.128	0.050
Electronics	10	10	0.114	-0.020
TRIDENT II D5 Missile (Navy)				
Electronics	10	10	0.095	-0.082
Electronics	0	0	0.159	-0.081
Electronics	0	0	0.143	0.132
Electronics	0	0	0.098	-0.080
Electronics	10	10	0.070	-0.048
Electronics	0	0	0.140	-0.012
Electronics	0	0	0.118	-0.050
TRIDENT II Submarine (Navy)				
Submarine Group IV	0	0	0.142	0.035
Submarine Group V	10	10	0.081	-0.024
UH-60A, Blackhawk Helicopter				
(Army)				
Airframe, Lot IV	0	0.1	0.113	-0.092
Airframe, Lot III	0	0	0.172	-0.175
Airframe, Lot II	0	10	0.056	0.019

Electronics	10	10	0.068	-0.038
Electronics	0	10	0.114	-0.126
Engine, Lot II	0	0	0.139	-0.103
Engine, Lot I	0	0	0.074	-0.009
Airframe, Lot I	0	20	0.141	-0.229
Engine	0	0	0.094	-0.057
Airframe	0	0	0.173	-0.179
V-22A Osprey Aircraft (Navy)				
Aircraft	0	0	0.183	-0.149

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Vita

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13. ABSTRACT (Maximum 200 words) This study examines approaches currently used to determine when Cost Performance Index (CPI) stability occurs. The CPI indicates the cost performance efficiency of the work the contractor has accomplished to date; however it has value as a predictor of future contractor cost performance given that the CPI can be declared stable. Knowing that the CPI is stable allows government personnel to project the final cost of the contract and, if a cost overrun is projected, to determine the likelihood that the contractor can recover. The range method was used to test for stability of cumulative and non-cumulative CPI values. The method measured the range of the CPI values that occurred after the 50 percent contract completion point. The results indicated that the cumulative CPI is more stable than the other CPIs examined, stabilizing from the 20 percent completion point. As a caveat however, the method of least squares showed that the cumulative CPI does tend to decline within the allowable range limit as the contract proceeds. Thus the final cumulative CPI value can be expected to be lower than the cumulative CPI value observed at the 20 percent contract completion point.				
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